July 1958

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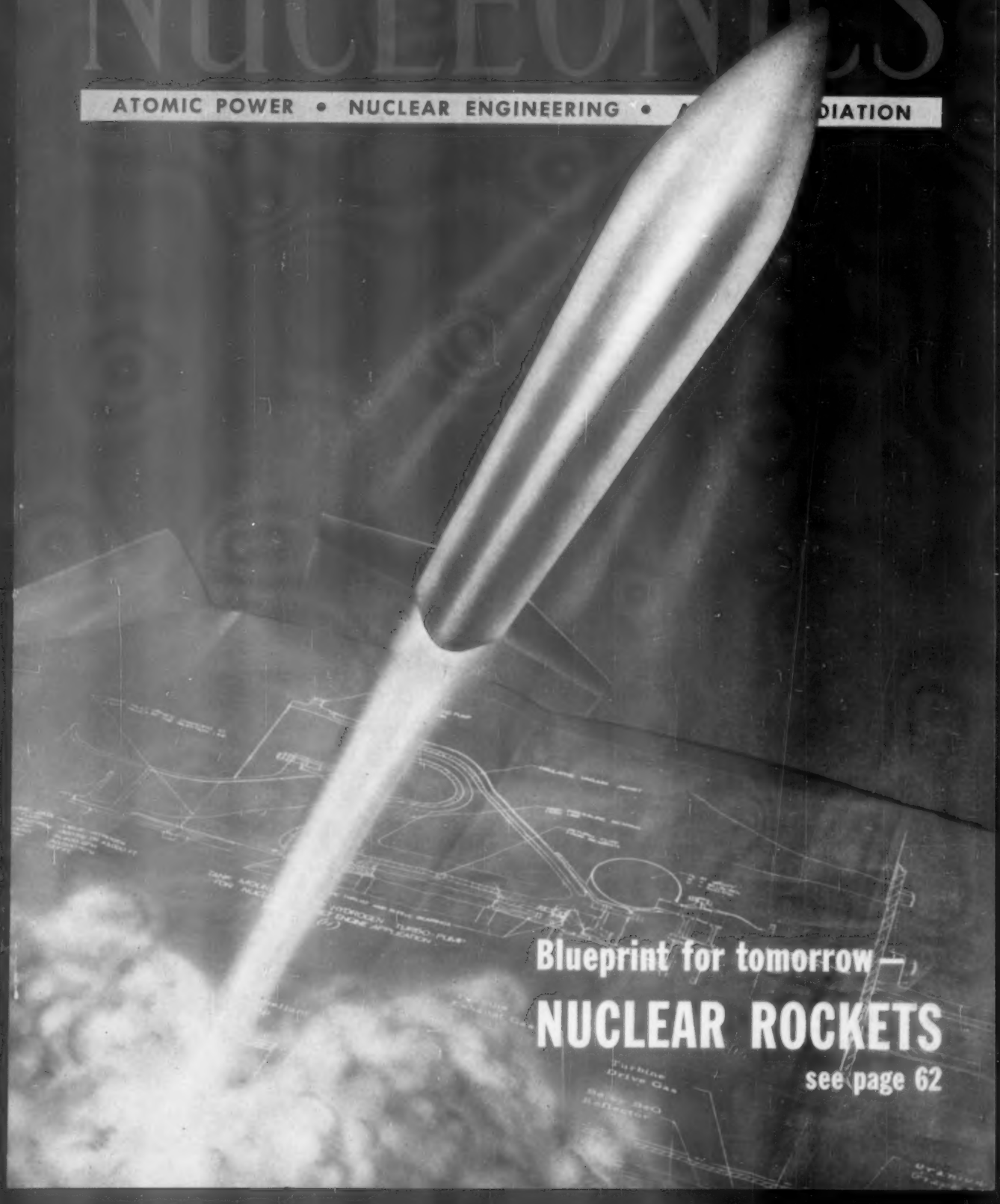
NUCLEONICS

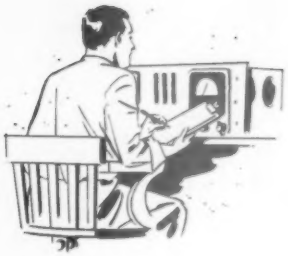
ATOMIC POWER • NUCLEAR ENGINEERING • A... DIATION



Blueprint for tomorrow—

NUCLEAR ROCKETS

see page 62



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NUCLEAR ENGINEERING
APPLIED RADIATION

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About NUCLEONICS

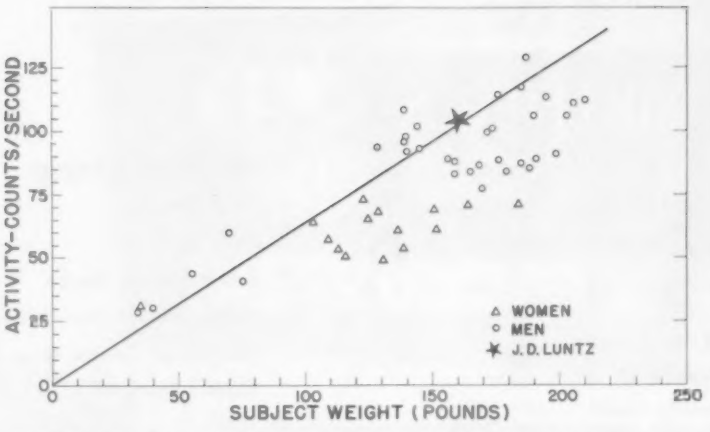
Western Odyssey

Two months ago in this space we reported the undersea adventures of one of our editors who had taken a cruise on the Seawolf. *We now continue the saga of our traveling editors as Editor Jerry Luntz tells of a three-week tour of nuclear facilities in the far west.*

As impossible as it is to "do" the Louvre in one afternoon—as I have tried—so it is getting more and more impossible to "do" the nuclear west in the U. S. in three weeks—as I tried to do again this year. Not only are there now many more activities than there were a few years ago, but installations that were once highly classified are now much more accessible to an uncleared editor.

I was particularly struck on this trip by the vastness and vigor of the U. S. nuclear enterprise, both governmental and private. We're doing lots of exciting things that will be paying off in the coming years.

Three vast, private enterprises have mushroomed in California, blanketing the state—General Electric's Atomic Power Equipment Department at San Jose and Vallecitos, the Atomics International Division of North American Aviation at Canoga Park and Santa Susana, and the General Atomic Division of the General Dynamics Corp. at San Diego. This undoubtedly represents the largest concentration in any one state of private talent devoted to civilian applications.



MUSCULARITY of Editor Luntz is attested by measurements E. C. Anderson made with Los Alamos' "human counter" (NU, Jan. '56, p. 27), which measures natural potassium activity in body. Muscle tissue generally has higher K content

All three companies are building extensive new facilities in typically California-like picturesque surroundings. General Atomic is well along on its laboratories and office buildings, including a special thermonuclear building. Although they've been operating in the Santa Susana Mountains for some time, Atomics International has just embarked on building $1.5-million worth of offices and labs there, including sodium component test facilities. GE's atomic power activity, a newcomer to California, is in full swing with fuel manufacturing facilities at San Jose and a vast laboratory at Vallecitos.

Particularly exciting at Los Alamos Scientific Laboratory were the four fusion exhibits that have been prepared for display at Geneva. Data is still being taken on the devices prior to their being shipped abroad. Two of the devices are expected to produce neutrons—not necessarily thermonuclear neutrons.

At the National Reactor Testing Station in Idaho, the Phillips Petroleum people were awaiting the arrival of a Hanford-produced plutonium core for loading into the Materials Testing Reactor. Following the Pu operation, it is hoped to load a U^{233} core.

The Organic Moderated Reactor Experiment in Idaho is also going quite well, with no noticeable gumming of the system by the decomposition products from the fluid. It's a delight to see the "casualness" of the plant—it's unpressurized and they hang pails on the pipes to catch any leakage!

—*The Editors*

Coming Features in NUCLEONICS

Next Month

Pre-Geneva Report
Nuclear Fuels
Reactors on the Line, No. 6—Oak Ridge Research Reactor

Later Months

Shock Waves in Reactor Containment
Graphical Aids for Shielding Calculations
Critical Facilities Report
Chemical Reprocessing—IV

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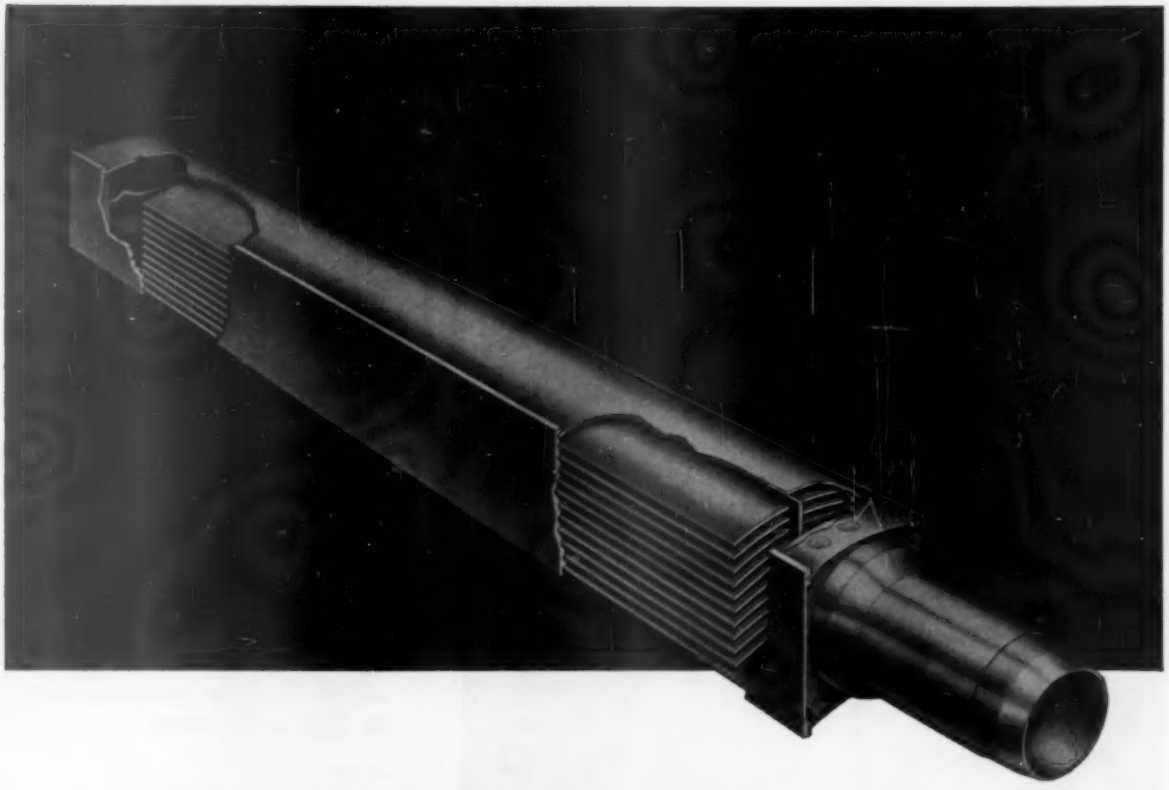

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Since entering the field of fuel element fabrication with the first privately financed facility for this purpose in the United States, B&W has supplied more than 1,500 fuel elements to more than a dozen reactor installations, both in this country and abroad. B&W pioneered in the manufacture of fuel elements for export containing uranium metal enriched to 20 per cent in U-235.

The manufacture of fuel elements at B&W is supported by almost 100 years of related experience.

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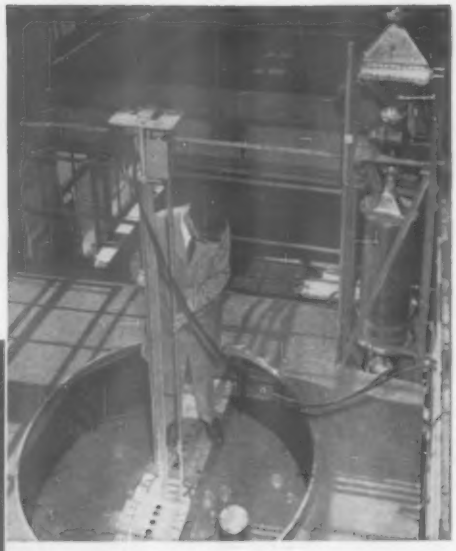
Another Canadair Nuclear Achievement:

University of Toronto's New Reactor represents important advance in

NUCLEAR ENGINEERING EDUCATION IN CANADA



Above:
Subcritical Reactor top view, showing the installation of the vertical ion chamber drive mechanism and the vessel drying system.

At left:
Subcritical Reactor showing reactor vessel, source flask, horizontal ion chamber drive mechanism, and counting rate recorders.

March, 1958, marked an important date in the field of student training in nuclear energy in Canada with the successful completion at the University of Toronto of Canada's first university-owned subcritical reactor.

The Subcritical Reactor, located in the University's Wallberg Building, was designed and built by Canadair's Nuclear Division, and will be used as a laboratory training tool for undergraduate students.

In the reactor, natural uranium rods sheathed in aluminum are mounted vertically in a cadmium-covered aluminum vessel. A heavy water moderator surrounds the rods and an external source of neutrons (yielding 10^8 neutrons per second), is mounted in a graphite pedestal situated below the vessel. Various fuel lattice spacings are possible through provision of alternative grid plates.

The Subcritical Reactor is inherently safe and requires no complicated control system, bulky shielding, or cooling system. As such, it is ideally suited for teaching purposes. Experimentation and instruction are facilitated by easy access to the reacting region through horizontal and vertical experimental tubes.

Although primarily designed for undergraduate training in Nuclear Engineering, the Reactor can also serve for a research program in the properties of heavy water reactors.

The Nuclear Division of Canadair has a unique group of nuclear scientists and engineers thoroughly experienced through a variety of successfully completed programs in the nuclear field. They are ready and eager to discuss your problem, present or potential, if it involves the application of Nuclear Energy in any way.

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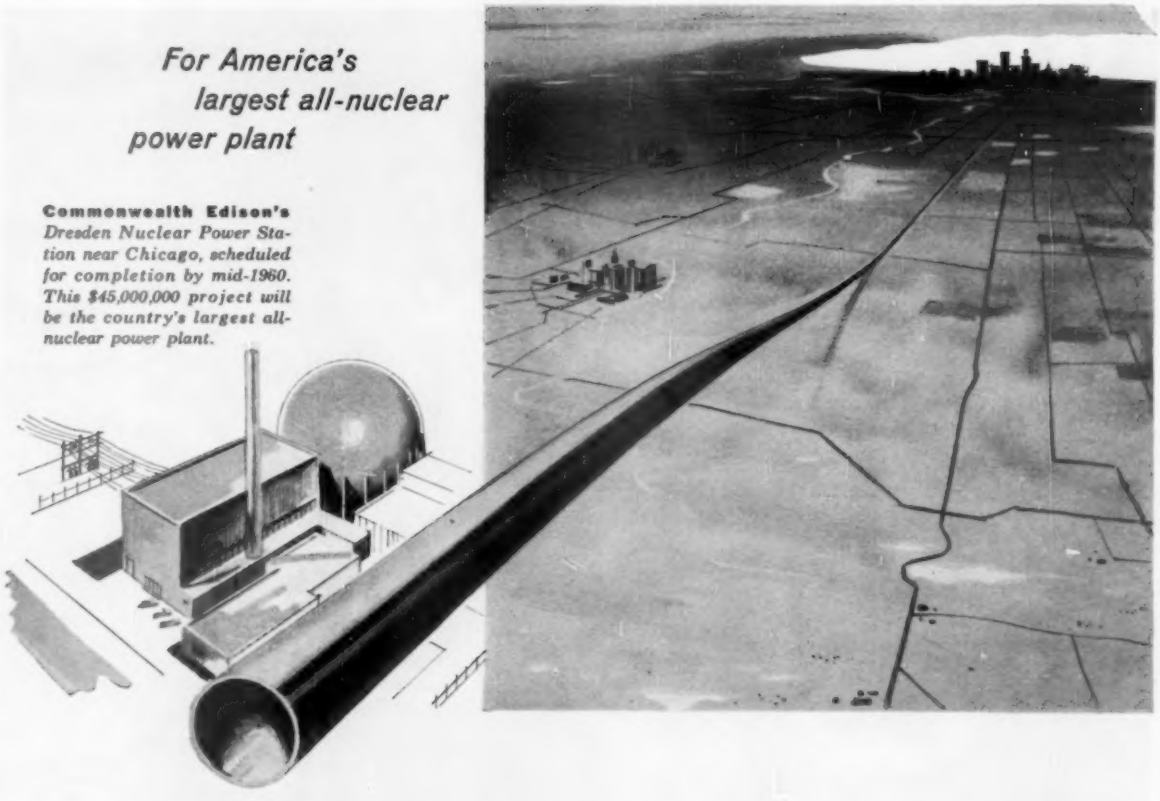
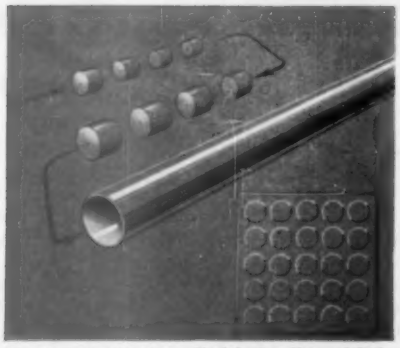
For America's largest all-nuclear power plant

Commonwealth Edison's *Dresden Nuclear Power Station near Chicago, scheduled for completion by mid-1960. This $45,000,000 project will be the country's largest all-nuclear power plant.*



44 MILES OF ZIRCONIUM TUBING

being processed by Mallory-Sharon



To form fuel rods, *cylindrical pellets of UO_2 are inserted in Zircaloy tubing. Tubes are sealed and welded, then assembled into "bundles" to form the rod-type element (inset).*

Here you see a striking example of zirconium's place in nuclear power . . . and of Mallory-Sharon's leadership in zirconium production and technology.

The largest order ever placed for zirconium tubing—almost 44 miles of it—is now being processed by Mallory-Sharon, in conjunction with Bridgeport Brass Co., for the Dresden Nuclear Reactor. Made of reactor-grade Zircaloy-2, 9/16" diameter and 1/22" wall thickness, the tubing must meet rigid tolerances . . . pass special pressure, sonic and corrosion tests. Fabrication of fuel elements is by the Atomic Power Equipment Dept. of General Electric, at San Jose, California, designers and builders of the Dresden Station for Commonwealth Edison.

As the largest integrated producer of zirconium, titanium and special metals, we invite you to write for information on either reactor-grade or commercial grade zirconium. Our Service Engineering group is ready to work with you *now* on either nuclear or commercial applications.

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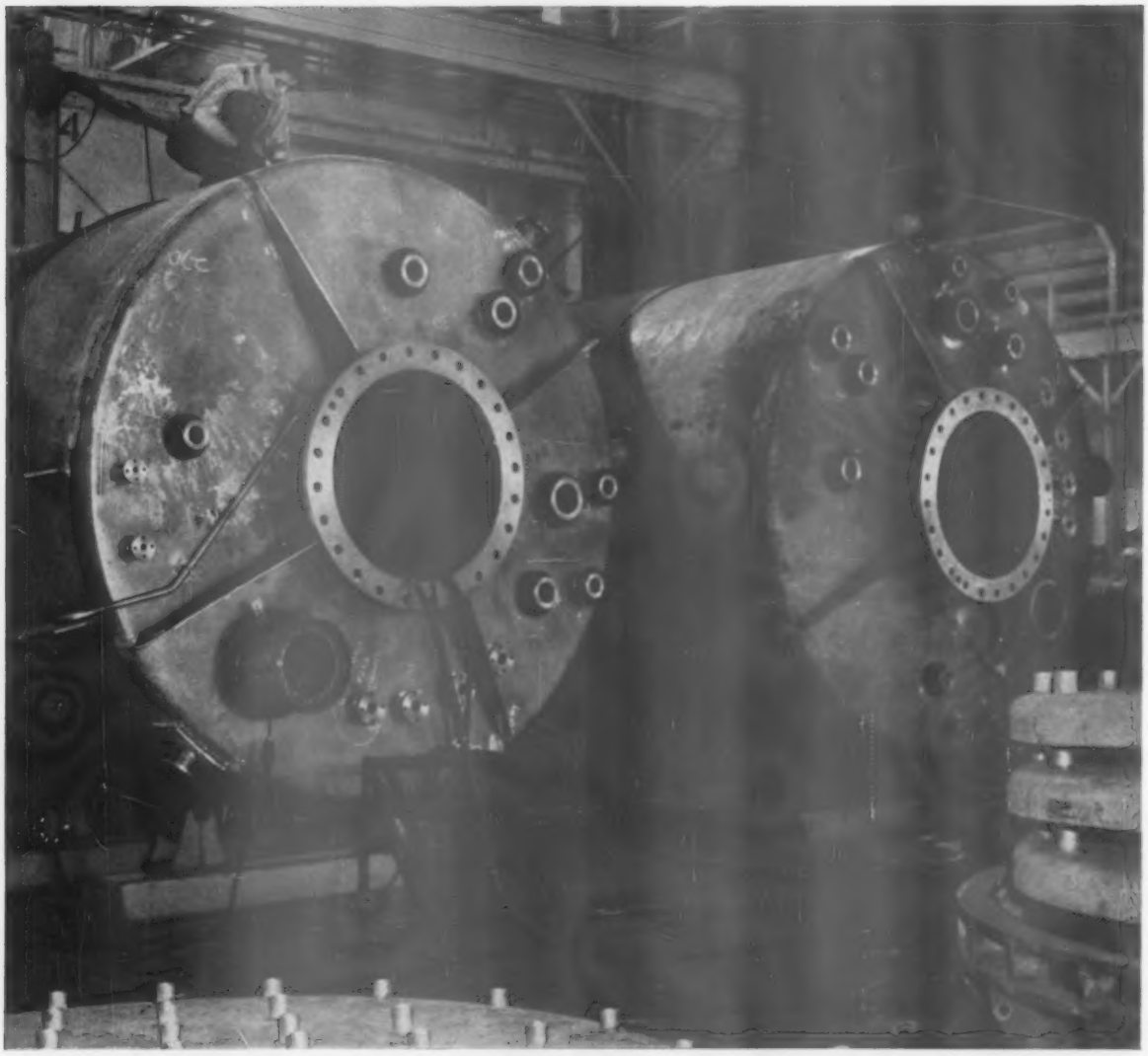

For Transferring Radioactive Process Wastes

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Ever since work on atomic reactors began, Graver has been building stainless tanks for transferring radioactive process effluents. Filled by remote control and cooled to remove heat from radioactive decay, tanks of the design shown above have been in service long enough to now be regarded as a standard for this use.

Stainless is useful for its ability to withstand either basic or acidic liquid wastes for a long time without serious corrosion. For mixed radioactive wastes with many "half-lives", such tanks may be required to hold dangerous isotopes for a very long time. The craftsmanship must be of the highest, which is never a question with Graver's hundred-year reputation for quality fabrication. For atomic energy use or for industrial wastes, stainless and alloy fabrication by Graver provides the complete answer for long-lived installations.

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THE PEACEFUL ATOM

...a sound investment for increasing power requirements

15 Utility Companies Underwrite Study For Advanced Nuclear Power Reactor For the Southwest

Up from the Texas Panhandle... through the oil fields of Oklahoma... across the Kansas prairie... over the Ozarks of Arkansas and Missouri... and down through the rich bottom land of Mississippi and Louisiana stretches a vast network of electric power lines and generating stations. Through this vital system surges millions of kilowatts of power... lifeblood of the Southwest's cities, farms and factories.

The bulk of this power (6,250,000 kw) is generated by fifteen investor-owned utility companies. Recently these firms made a decision that brings peaceful atomic energy into an important new phase.

Planning together as the Southwest Atomic Energy Associates, they signed a multi-million dollar contract with Atomics International to develop an advanced reactor concept for full-scale atomic-electric power stations. The new project is called AETR (for Advanced Epithermal Thorium Reactor). It promises to be economically competitive with power plants that depend on diminishing, increasingly expensive conventional fuels. Studies will be directed toward the design of a nuclear power plant of 200,000 electrical kilowatts.

NEW POWER FOR THE SOUTHWEST
Fifteen companies pool resources to develop an advanced power reactor

Interest in the project is indicated by a roster of the new group's member companies: Arkansas Power and Light Co., Arkansas-Missouri Power Co., Central Louisiana Electric Co., Inc., Empire District Electric Co. (Mo.), Gulf States Utilities Co., Kansas Gas and Electric Co., Kansas Power and Light Co., Louisiana Power and Light Co., Mississippi Power and Light Co., Missouri Public Service Co., New Orleans Public Service, Inc., Oklahoma Gas and Electric Co., Public Service Co. of Oklahoma, Southwestern Gas and Electric Co. (La.), and Western Light and Telephone Co., Inc. (Mo.).

ing Station in Idaho Falls since last September. It has provided technical and economic information for the construction of OMR power plants now planned for the City of Piqua, Ohio, and large network installations under consideration for this country and abroad. Atomic propulsion systems for supertankers and merchant ships are another important OMR application.

In addition, Atomics International research reactors are helping to bring "Atoms for Peace" to the free world.

SEVEN STATES MAP OUT A PLAN FOR ATOMIC ELECTRICITY

Hardware in Action. AI has built and is now operating two other nuclear power reactors as part of the AEC's program for economical power from atomic energy. One of these is the Sodium Reactor Experiment (SRE) which is supplying nuclear heat to operate an experimental electric power plant installed by the Southern California Edison Co. The SRE is providing technical data and experience for the design of full scale electric stations, such as the 75,000 kw plant for Consumers Public Power District of Nebraska.

AI's Organic Moderated Reactor Experiment (OMRE) has been operating at the AEC's National Reactor Test-

These reactors are now operating in Japan, Germany, Denmark, and the United States. Another is under construction for Italy.

Nuclear Power Abroad. AI works with leading companies overseas. With DEMAG, one of West Germany's largest heavy manufacturers, AI has formed INTERATOM, a jointly owned subsidiary headquartered in Duisburg. AI has a technical assistance agreement with ASEA, a prominent Swedish electrical firm with offices in over 50 countries.

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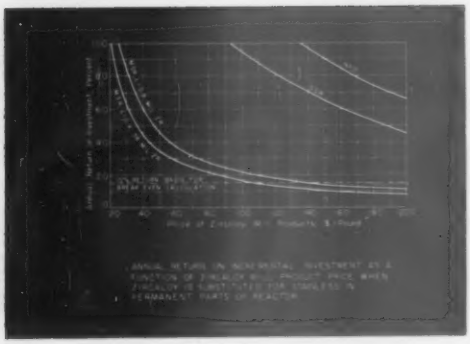
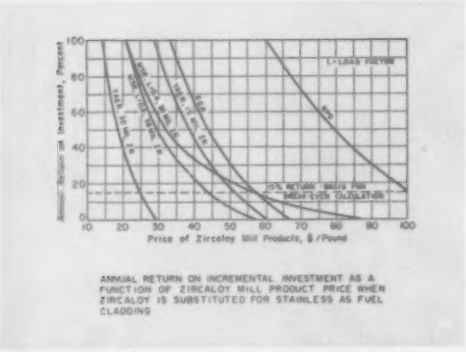
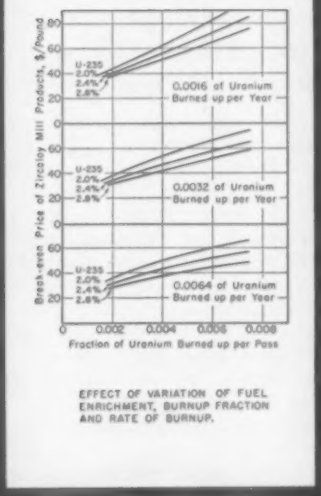
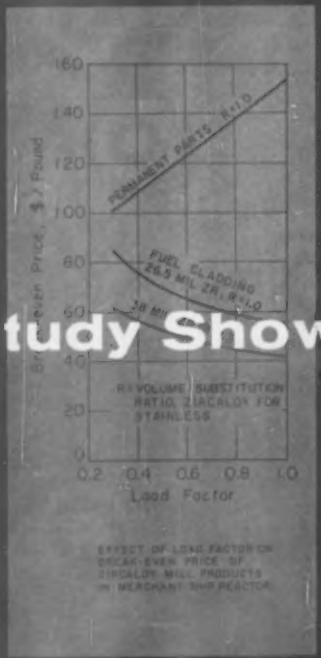



Annual Return on Investment, Percent
Price of Zircaloy Mill Products, $/Pound
LI-LOAD FACTOR
10% RETURN - BASIS FOR BREAK-EVEN CALCULATIONS

ANNUAL RETURN ON INCREMENTAL INVESTMENT AS A FUNCTION OF ZIRCALOY MILL PRODUCT PRICE WHEN ZIRCALOY IS SUBSTITUTED FOR STAINLESS AS FUEL CLADDING

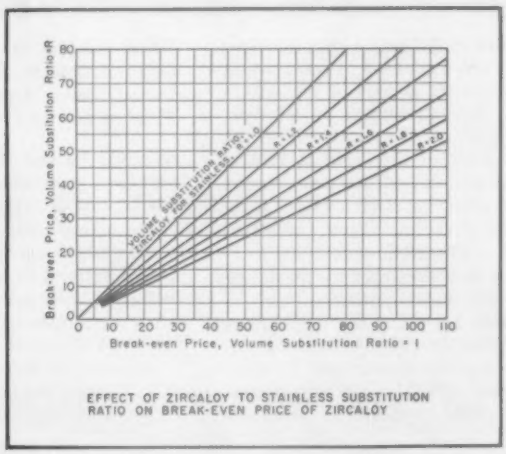

Break-even Price of Zircaloy Mill Products, $/Pound
U-235
2.0%
2.4%
2.8%
0.0016 of Uranium Burned up per Year
0.0032 of Uranium Burned up per Year
0.0064 of Uranium Burned up per Year
Fraction of Uranium Burned up per Pass

EFFECT OF VARIATION OF FUEL ENRICHMENT, BURNUP FRACTION AND RATE OF BURNUP.



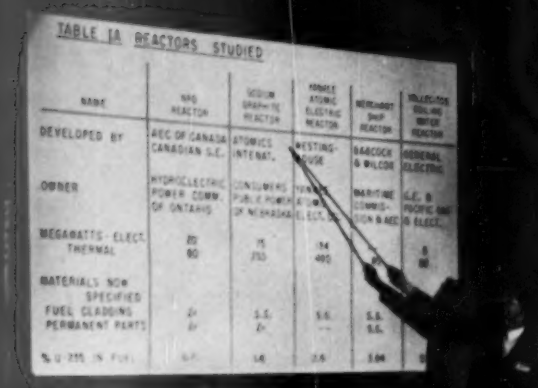
EFFECT OF LOAD FACTOR ON BREAK-EVEN PRICE OF ZIRCALOY MILL PRODUCTS IN MERCHANT SHIP REACTOR

Columbia-National Study Shows...

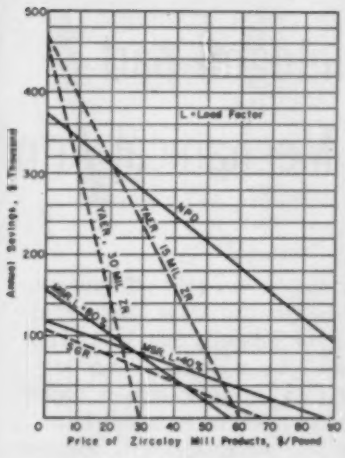


EFFECT OF ZIRCALOY TO STAINLESS SUBSTITUTION RATIO ON BREAK-EVEN PRICE OF ZIRCALOY

NEW METALS FOR INDUSTRY



Dr. Manson Benedict, head of the Nuclear Engineering Department at M.I.T., points to data on the reactors studied, at a recent symposium held to present the results to industry representatives.



ANNUAL SAVINGS IN DIRECT OPERATING COSTS FROM THE SUBSTITUTION OF ZIRCALOY FOR STAINLESS STEEL IN FUEL CLADDING

how to Save Money with ZIRCONIUM

The relative values of zirconium and stainless steel in five power-producing nuclear reactors have been studied for Columbia-National by Dr. Manson Benedict.

This study shows that the low neutron absorption of zirconium (or Zircaloy) can often contribute important savings through the use of uranium of lower enrichment, through reduction in the critical mass of uranium, or through some combination of these features. The effects of changes in the principal design variables have been studied to make the results applicable to a wide range of reactors.

A summary of the results of this study will be sent to those requesting it on business letterheads.

Columbia-National Corporation

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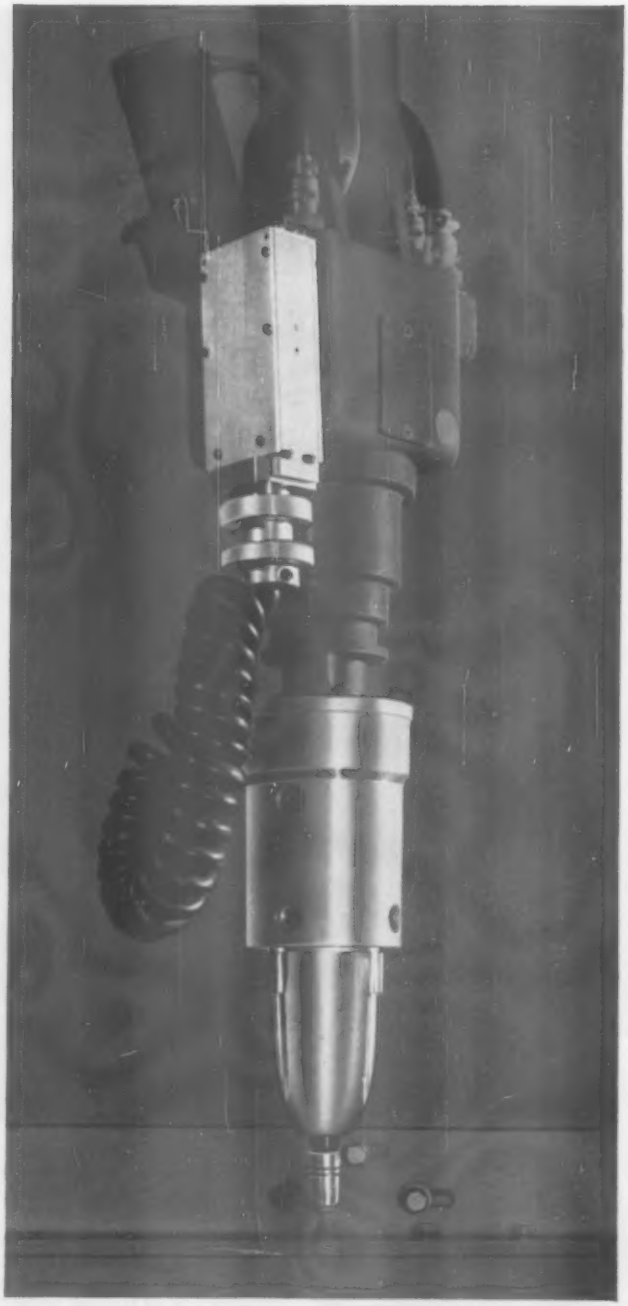
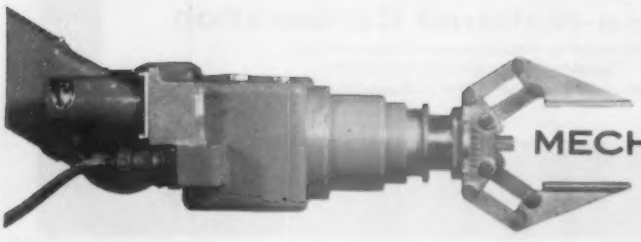


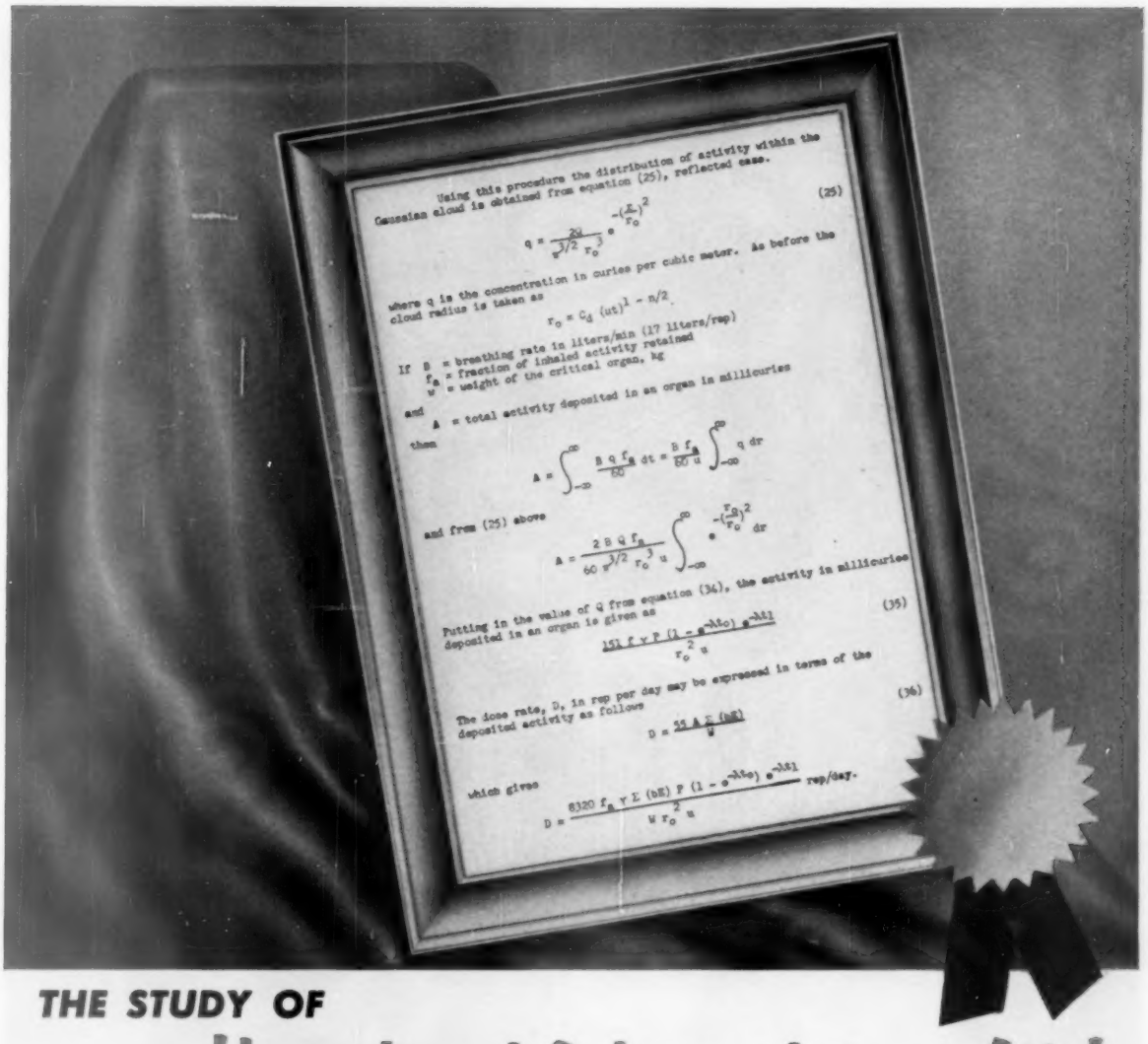
POWER TOOLS EASILY ATTACHED TO MECHANICAL ARM: tools snap into place on the forearm. A simple electrical connection at the power take-off, which is permanently mounted on the forearm, completes the placement.



General Mills

MECHANICAL DIVISION

Minneapolis, Minnesota


Using this procedure the distribution of activity within the Gaussian cloud is obtained from equation (25), reflected case.
(25)
where q is the concentration in curies per cubic meter. As before the cloud radius is taken as
If B = breathing rate in liters/min (17 liters/rep)
f_a = fraction of inhaled activity retained
w = weight of the critical organ, kg
and
A = total activity deposited in an organ in millicuries
then
and from (25) above
Putting in the value of Q from equation (34), the activity in millicuries deposited in an organ is given as
(35)
The dose rate, D, in rep per day may be expressed in terms of the deposited activity as follows
(36)
which gives
rep/day.

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from Donald W. Douglas, Jr.

President, Douglas Aircraft Company

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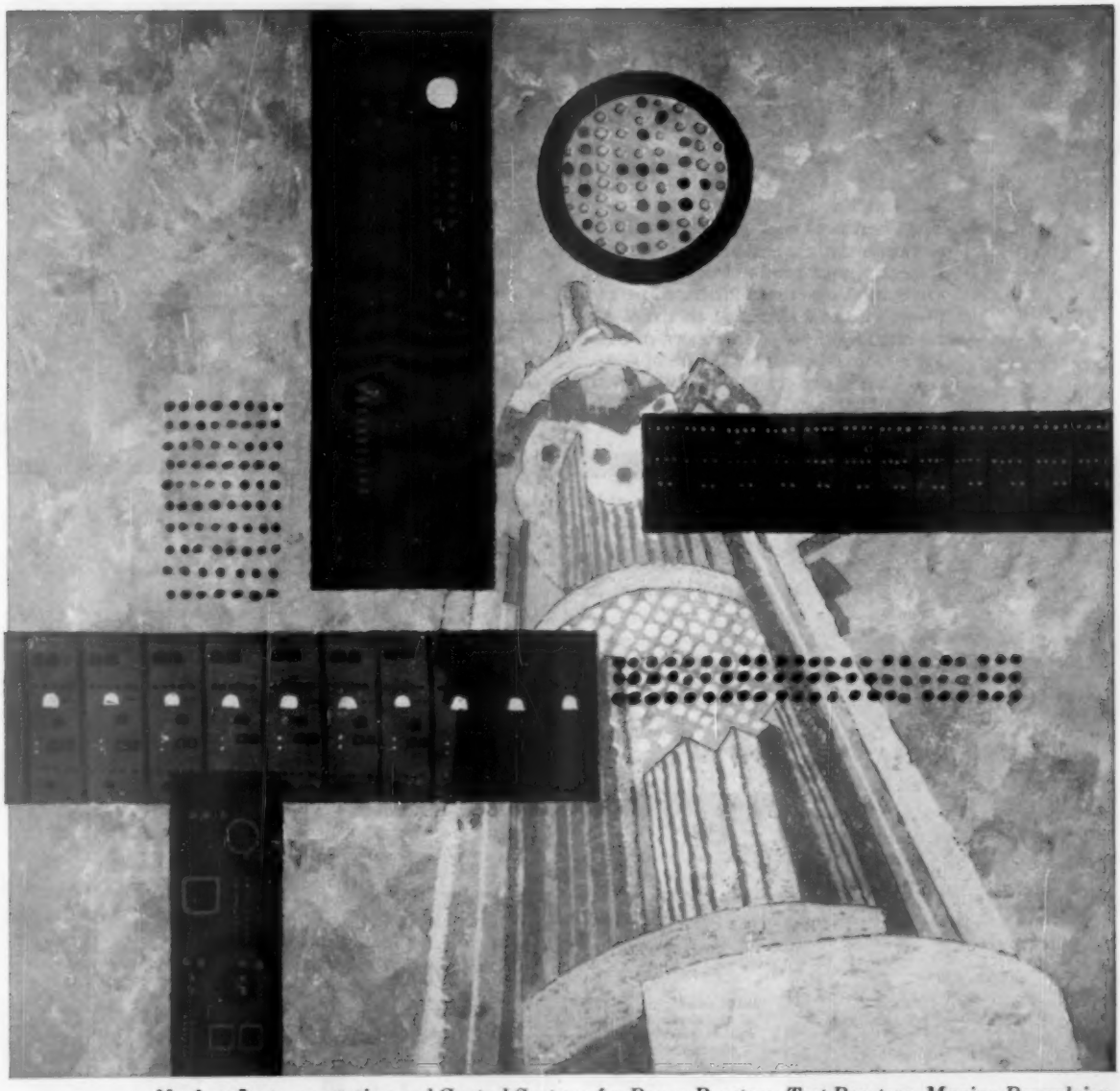

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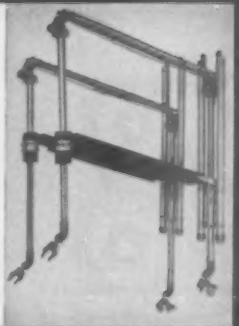

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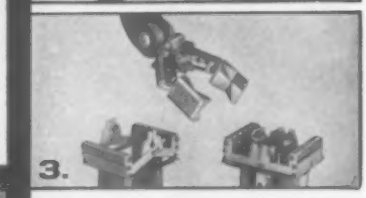

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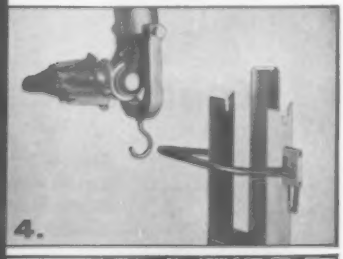

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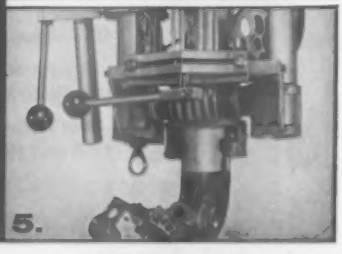

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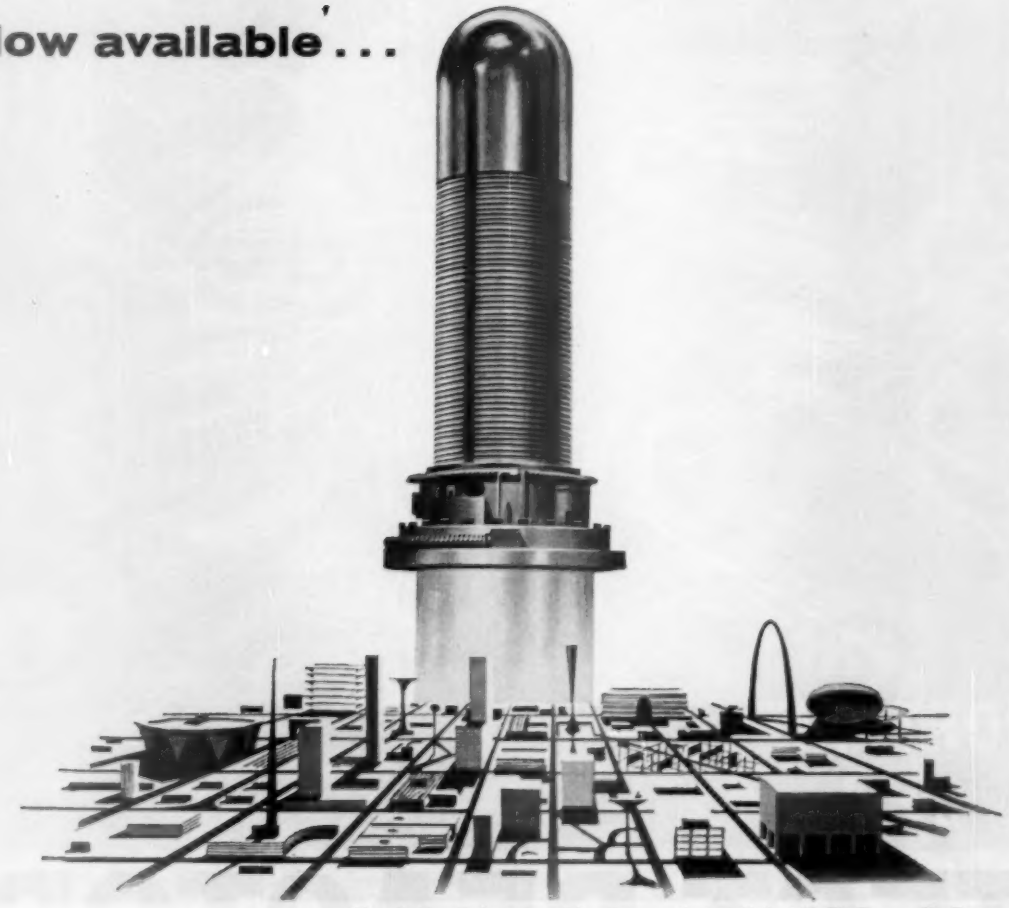

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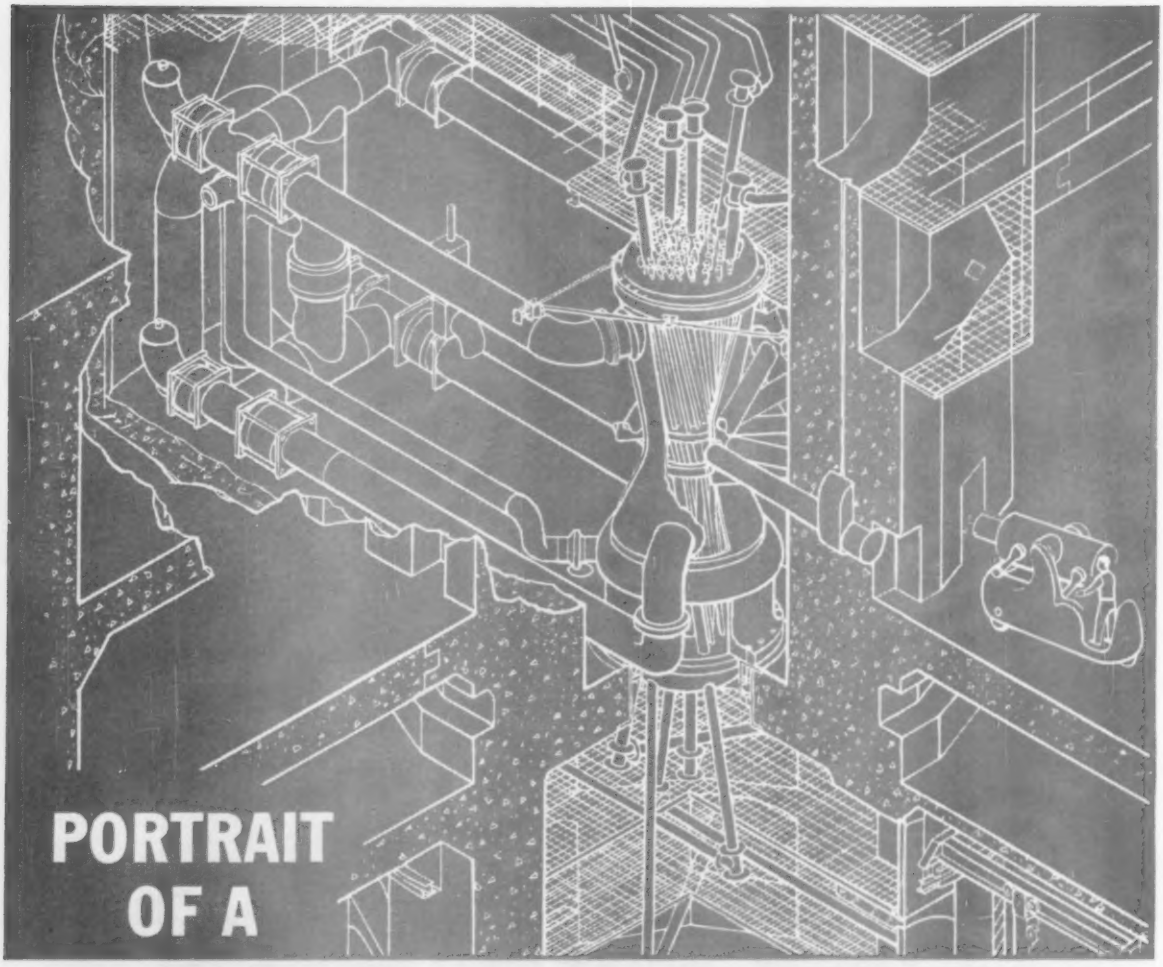

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NDA's complete reactor capabilities are exemplified in METR (above), a 50-megawatt Materials and Engineering Test Reactor, the first of which is now under construction at Mol, Belgium. Beginning with the core itself, a unique design which combines extremely high neutron flux with simple, independent access to each fuel and experiment tube, METR I will be a vital part of one of the world's great nuclear centers. METR is typical of the family of reactors now under design or development at NDA for power, propulsion and research.

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ROUNDUP of Key Developments in Atomic Energy

AEC, JCAE Agree to Speed Up U. S. Reactor Program

Walking separate but—at last—converging paths, the Atomic Energy Commission and the Joint Committee on Atomic Energy last month agreed to accelerate the U. S. civilian power reactor program. Moreover, the two governmental bodies appear to be well on the way toward restoring the good working relationship that must prevail if an accelerated program is to proceed smoothly.

A month of rapid-fire events, which brought an entirely new and more vigorous posture to the U. S. atomic energy effort, was culminated June 30 when Lewis L. Strauss stepped down from the AEC chairmanship in favor of John A. McCone, West Coast businessman (see p. 20). Before Strauss switched to an advisory post at the White House in the atoms-for-peace program, there were these developments:

- AEC and JCAE, completing six months of negotiations in which Strauss took a back-seat role, restored a measure of personal goodwill to their relations and publicly agreed that the U. S. should speed up its reactor program to aim for the achievement of economic nuclear power in the U. S. within ten years and in friendly foreign countries within five.
- To this end, AEC and JCAE proposed separate—but similar—reactor construction programs covering the next 5–7 years (*see table, p. 18*). A major and significant difference is this: AEC's acceleration program would not get off the ground until next year, (except for an increased effort on the fuel cycle) because of a Budget Bureau crackdown on the AEC building program for the fiscal year which began July 1 (NU, June '58, 18).
- Bowing to JCAE pressure for a more aggressive reactor policy, AEC dropped its insistence that industry get first crack at building all first-generation reactors. AEC will assume greater control over prototype construction by designating concepts ready for this step and by sponsoring any project which might be delayed by industry sponsorship.
- JCAE, unhappy with AEC's fiscal '59 program as trimmed sharply by the Budget Bureau, voted a doubling of the program from just under $200-million to almost $400-million; several reactor projects and $35-million in research facilities were added (*see p. 22*). Thus, AEC has lost the initiative on the extent of acceleration this year, first to the Budget Bureau, then to JCAE.
- President Eisenhower asked Congress to approve a program of cooperation with Euratom before Congress adjourns this summer; favorable action would bring a stepped-up effort on both sides of the Atlantic to make nuclear power competitive (*see p. 24*).
- A continuing personnel shakeup at AEC (*see p. 21*) made it clear that, when the smoke clears, the Commission will have new leadership not only in the chairmanship and in the general manager's office, but also in Reactor Development.

With the resignation of Strauss, (based primarily, he said, on circumstances beyond his control) the feud with JCAE Democrats has

U. K. civil stations to make war Pu; Japan reacts

In a surprising about-face, Britain has put an end to the separation of its military and civil reactor programs with the announcement that future civil power stations beginning with Hinkley Point will be modified to make plutonium for weapons rather than fuel use. The new policy slashes military Pu costs and is also seen as a means of enabling the government to offer its Central Electricity Generating Board a more favorable credit for spent fuel elements. The Ministry of Defense announcement said only that the step was taken "to provide insurance against future defense needs"; officials declined to say if last fall's accident forcing shutdown of the Windscale Pu plant (NU, Nov. '57, 130; Dec., 43) necessitated the move. Main effect of the change will be to drop the fuel-element life to about ⅓ the current optimum economic value on which (together with Pu buyback price) the current nuclear power cost structure was determined. A 4-yr life had been anticipated, based on a rating of 3,000 Mwd/ton.

Reaction—disappointment—in Japan was immediate. When word reached Tokyo that the Calder-type export model may not be a stepped-up version as had been anticipated, speculation grew that Japan may not buy British after all. Heightening speculation was this fact: in Premier Kishi's reshuffled cabinet, tough old Matsutaro Shoriki was replaced as atomic czar by younger, American-educated Takeo Miki. Waiting at Miki's elbow to help persuade him to abandon buy-British plans are Japan's three biggest heavy electrical equipment firms, Mitsubishi, Hitachi and Tokyo Shibaura, all three with important ties to U. S. firms. Bids by three British equipment suppliers are due July 31.

Second Calder turbine explodes

Eight months after Windscale came another blow to the U. K. atomic program. Calder "B," the second two-reactor plant adjoining the pioneer station, was extensively damaged when its $750,000 turbine, being tested prior to startup of the second station due shortly, overheated and literally disintegrated "through sheer centrifugal force." Blast carried a shower of metal through the turbine hall, walls and roof; flying metal fractured water mains and the wrecked turbine hall was flooded. The two reactors at Calder "A," operating since October 1956, were unaffected.

come to an end. The feud was officially buried on June 18 in a conciliatory speech by Sen. Clinton P. Anderson (D.-N. M.) to the Nuclear Energy Writers Association. "I am willing to let the dead past bury its dead and go on to happier days," he said.

The Senator also proposed direct federal subsidy of reactor construction, to be awarded to reactor projects in the ratio of existing publicly- and privately-owned electrical capacity—1–4; AEC would pay up to 90% of the difference in the cost of nuclear and fossil-fueled power plants of the same size and location. The idea has been suggested before by Lawrence Hafstad, then of AEC, and by Willis Gale of Commonwealth Edison—but Anderson is the first JCAE member to espouse it.

JCAE Forces Acceleration

Regardless of the outcome of Anderson's subsidy suggestion, there is little question in Washington that the Democrats have successfully forced acceleration. JCAE chairman Carl Durham (D.-N. C.), who proposed the acceleration talks which began in December, had called for a joint AEC-JCAE effort. By mid-March, however, when he spoke to the Chicago industry meeting (NU, Apr. '58, 17), he was warning that JCAE would act unilaterally if AEC failed to offer an "adequate program." By mid-April, with the Budget Bureau having become a powerful party in the negotiations, the Democrats had decided to act.

They composed a program which is essentially a hybrid. Its nucleus is the ten-year program suggested earlier this year by a task force of the Edison Electric Institute (NU, Apr. '58, 20). It was put in its final form by a panel of reactor and industrial engineers especially convened by the Committee for this job (Walter H. Zinn, General Nuclear Engineering; Henry D. Smythe, Princeton; Chauncey Starr, Atomics International; Titus LeClair, Commonwealth Edison; and James Grahl, American Public Power Assn.).

While the Committee was moving ahead with this effort, AEC was running into an unprecedentedly tough reception at the Budget Bureau on both its '59 and its long-range programs. What came out of these "negotiations," according to disgruntled JCAE Democrats, was a watered-down version of the '59 program and a less-than-adequate long-range program (the entire package was formally presented to the JCAE on June 3 by Commissioners Vance, Graham and Floberg).

Disappointed with the AEC presentation, the Committee Democrats immediately took to the task of 1. beefing up the '59 program and 2. pressing AEC for formal agreement to a long-range schedule of possible reactor construction which both sides could accept. As to the '59 program, at least one Commissioner, fed up with AEC's treatment at the hands of the Budget Bureau, said he would welcome Democratic expansion. As to the long-range program, an AEC-JCAE compromise was seen as little more than a formality because the schedules suggested by each were so much alike and because both were conceded to be only tentative, subject to year-by-year changes in reactor technology.

The Proposals

The JCAE version, for example, totals 20 reactors but "only about half" are expected to go beyond design and feasibility studies, according to Anderson. As proposed, however, the program would call for the expenditure of $1.3–1.5-billion over the next seven years: $875-million for capital and operating expenses and $100-million annually for research and development.

AEC's program, covering the period 1958–63, was not added up in terms of estimated cost but, as Anderson pointed out after seeing it, runs strikingly parallel to the JCAE program. "There is little disagreement [between AEC and JCAE] as to the projects which should be undertaken in any expanded program," he emphasized.

Where, then, is the area of possible disagreement, if any, on a long-range program? The answer is that it's in the same place it has always been—behind the door marked "federal-versus-private enterprise." AEC, heretofore adamant about proceeding with federal sponsorship of reactors beyond the experiment stage, has now agreed to build prototype plants when private sponsorship would hold back development of

AEC and JCAE Reactor Programs Compared

	*Years of development and size in Mw(e)**	
Reactor project	*JCAE*	*AEC*
D_2O components test	1956–1960, 60 (th)	1958–1961
Gas-cooled graphite-moderated	'58–'62, 40	'58–'62
Boiling water, nuclear superheat	'58–'62, 10–30	
D_2O-moderated and -cooled	'58–'63, 100–250	'60–'63, 100
Aqueous homogeneous	'59–'65, 75–150	'59–-, 75–150
Process heat	'59–'62, 0–45 (th)	'60–-
Fused-salt fueled	'59–'64, 10	'60–-, "intermed."
2-region aqueous homogen. experim.		'60–'61
Steam-cooled, D_2O-moderated	'59–'65, 10	
Intermediate-energy breeder	'58–'67, 10	
Water-cooled, graphite-moderated (Hanford type)	'59–'64, 300–700	
Pressurized water, enriched U[1]	'59–'64, 200	'61–-
Boiling water, enriched U[1]	'60–'65, 200	'61–-
Organic-moderated and -cooled[2]	'60–'64, 50	'60–-
Two small 2d-generation industrial reactors[3]	'61–'65, 15–40	'61-'63–-
EBR-3		'61-'63–-
High-temp. gas-cooled, graphite- or D_2O-moderated	'61–'66, 200	'61-'63–-
Plutonium test reactor		'61-'63–-
High-temp. sodium-cooled, graphite- or D_2O-moderated	'62–'67, 200	'61-'63–-
Process heat (one or more)		'61-'63–-
Organic-moderated and -cooled[4]	'62–'67, 200	
Sodium-cooled, fast or intermed. breeder	'63–'68, 200	
Liquid-metal fueled[5]	'63–'68, 50	

*—Size given in Mw(e) except where Mw(th) is specified
1—AEC proposes 2–4 large-scale water reactors
2—AEC proposes a second experimental OMR; JCAE says second OMR can be commercial size
3—AEC proposes one small-scale PWR in 1960, 1–2 small-scale water reactors 1961–63
4—AEC proposes "one or more" organic reactors 1961–63
5—AEC proposes LMFRE-2, dual- or single-region
NOTE—Table does not include reactors proposed by AEC that are already underway such as LMFRE-1, Elk River, Piqua projects. JCAE program now undergoing revision

given concepts. With this concession won, however, Anderson went a step beyond to propose a subsidy program. Eventually, AEC may give in to the arguments for capital subsidies as it has done on the question of prototype construction but, for the foreseeable future, AEC shows no sign of agreeing to construction subsidies or anything else which would drastically modify the effort to build up an industry independent of government aid.

This was the gist of langauge carefully inserted in AEC's statement before it was presented to JCAE early in June. Read by Vance, it first conceded that: "A statement of long-term policy and objectives of the government on nuclear power development is desirable, if not essential in order to improve stability and facilitate planning by the industry." Then AEC warned:

"The desirability of facilitating planning and maintaining a certain minimum momentum in the nuclear power industry is *not* to be taken as an intent to support all who are in the field or who may want to get into the field. . . .

"It is important that competition be preserved, but the program objectives must be achieved by establishing a sound technical and economic basis for a nuclear power industry, not by artificial and premature expansion of the industry."

AEC's New Policy

With this preface on the record, Commissioner Vance went on to outline AEC's new reactor development policy:

1. The urgency of nuclear power development in the U. S. is dictated primarily by the need for this country "to maintain a position of technological leadership in the nuclear field" and to help friendly nations achieve nuclear power "as soon as possible." Because of nuclear power's importance "to their basic economics, curtailment of the need for increasing importation of fossil fuels will not brook delay."

2. The U. S. reactor program must continue to explore a considerable number of concepts, must include a number of experimental reactors, and must include the building of several generations of plants of successively improved designs.

3. Any financial assistance from the government will be rendered in a manner "which preserves normal industrial incentives and relationships and should accord equitable treatment of public and private power groups to the fullest extent possible."

4. An annual review of the U. S. program "will be carried out vigorously"; projects that may completely lose their promise will be eliminated and emphasis on projects carried forward will be adjusted to their relative degree of promise.

5. AEC will continue to support a broad base of technological development, increasing immediately its effort to cut fuel cycle costs.

6. The cooperative policy on reactor construction will be continued but with a new emphasis—

a. AEC will continue its responsibility for research and development on new concepts and the construction of reactor experiments (though not excluding private participation in experimental work).

b. Reactors beyond the experimental stage (prototypes) will be assured of construction via this approach: AEC will remain open to proposals from industry for research and development assistance (AEC plans to carry forward the power demonstration program to December 31, 1959 for receipt of proposals and June 30, 1964 for completion of proposed plants); AEC will give itself the choice of proceeding with construction or polling private interest when a promising concept is not moving ahead on schedule. Once AEC assumes responsibility for a project, it will determine the site and specifications, then permit industry participation only when such participation would not cause delay in construction.

c. When a project is to be cooperative but does not completely satisfy the criteria of the demonstration program, AEC will request specific authorization from Congress.

7. To promote the goal for achieving economic nuclear power in friendly foreign areas within five years, AEC will press for adoption of a policy paper putting "into one package all of the various items of assistance" the U. S. is prepared to offer foreign reactor builders. AEC proposed that these items be considered (some of which are already part of U. S. policy or have been included in the agreement with Euratom (*see p. 24*)):

a. A statement covering the availability of U. S. technology and scientific knowledge on nuclear power.

b. A pledge to supply the enriched uranium required to operate each reactor over its amortizable life.

c. Reasonable assurance of the availability, at acceptable prices, of fuel cycle services, including a statement showing what the government's prices will be until the services are available elsewhere.

d. Contracts to purchase plutonium produced abroad for a reasonable period.

e. Sale, outright or on the installment plan, and, when appropriate, lease of enriched fuel inventory.

f. Export-Import Bank capital loans for nuclear plants on the same basis as loans for conventional units.

g. Continuation and expansion, if necessary, of U. S. facilities for training foreign reactor technicians.

h. Some means for solving the problem of third party liability as it affects American manufacturers within a framework recognizing that the U. S. can only urge early solutions to problems resting with the foreign nations concerned.

i. A firm U. S. declaration to support an expanded fuel cycle development program.

Makepeace, Nuclear Metals And Sylcor Share Big Fuel Job

In the first instance of the fuel fabrication job for a large-scale power reactor being contracted out to the new fuel-element industry, two $1.3–1.5-million contracts for production of the first fuel loading (and a spare core) for the Enrico Fermi fast breeder at Lagoona Beach, Mich., were let last month. The job will be shared by Sylvania-Corning Nuclear Co. and a team of D. E. Makepeace (a division of Engelhard Industries) with Nuclear Metals Inc.; each will make, by mid-1960, about half the blanket and an entire core. The contracts call for each group to make 100 of the 27%-enriched core elements (144 clad pins per element), with axial-blanket portions at either end (only 91 are required for one core); and 300 depleted-U radial-blanket elements (272 required). Sylcor will do its job at its Hicksville, L. I., plant. Makepeace will melt and cast the U-molybdenum alloy, Nuclear Metals will extrude it to billet size, return it to Makepeace for insertion into a cladding sleeve (zircaloy for core pins, stainless steel for blanket rods); then Nuclear Metals will perform the final coextrusion bonding meat and cladding, and Makepeace will assemble the elements (NU, April '57, 71). Full-scale production is to start by fall.

ROUNDUP

In Line to be AEC's Fourth Head: John A. McCone

With curiosity, hope—and high expectations, the atomic energy world last month was scrutinizing a silver-haired, deceptively-professorial-looking Californian on whom depended, in great part, the shape of the future U. S. atomic industry.

Nominated to AEC, and in line to be fourth chairman of the 11-year-old agency, is John Alex McCone, 56, construction engineer, industrialist, shipping magnate and former undersecretary of the Air Force, with no previous direct experience in the atomic field but a great reputation as an administrator.

Although he was nominated only for membership on the Commission, he told JCAE (when its Senate members unanimously approved him) that his designation as chairman awaits only Senate confirmation of his membership. (The Senate must pass on all nominations for membership on AEC, but selection of its chief is a Presidential prerogative.) Senate confirmed July 9.

How welcome McCone's nomination was on Capitol Hill was made tacitly clear even by Democrats in Congress. If they did not say so overtly, it was because the Senators, who must confirm all Commissioners, take the position that before they give their stamp of approval to any candidate, they must for their own protection satisfy themselves that the nominee's record contains nothing that might later reflect on those who approved him. Happily, even the long-embattled Democrats of the Joint Committee on Atomic Energy appear disposed to accept McCone, a registered Republican, as nonpolitical on atomic matters until and unless he should prove himself otherwise. They appear unconcerned by McCone's past ties with the "Old Guard" wing of Republicanism (a major money-raiser for Senator William Knowland's current gubernatorial campaign, he was strongly backed for AEC by Vice-President Nixon, and is a personal friend of former President Hoover). Actually, he has served with distinction under both Truman and Eisenhower administrations.

Some comments by members of Congress: "seems to have good qualifications," "very vigorous type of man," "tough-minded, very cold and analytical in his judgments [yet] has a way of getting along with people—doesn't have personality clashes with people under him."

"His background in big engineering is unusually good," was another Congressional comment.

John McCone's first job was as a riveter and boilermaker in a Los Angeles iron works—after he obtained his B.S. in engineering from the University of California at Berkeley in 1922. He became a superintendent in 1929, and by 1933—at 31—had become executive vice-president and director of the firm, Consolidated Steel Corp. In 1937 he left to help found—and to head—Bechtel-McCone-Parsons Corp. specializing in design, engineering and construction of refineries and power plants.

During the war Bechtel-McCone-Parsons built a huge center at Birmingham, Ala., for modification of B-24 and B-29 bombers; but by this time McCone had also become president and a director of California Shipbuilding Corp., which built 467 vessels worth $1-billion for the war effort. After the war he became head (and sole owner) of Joshua Hendy Corp., a one-time iron works which he transformed into a shipping firm that now operates 40–50 freighters and tankers. From 1948 to 1953 he also served as chairman of the board of the Pacific Far East Line. He is now resigning as head of Hendy to avoid any conflict-of-interest situation.

Government Career

In 1947, President Truman first called McCone to Washington to serve on the Air Policy Commission under Thomas K. Finletter. He helped write the "Finletter Report," *Survival in the Air Age*, and first met Dwight Eisenhower when the latter appeared before the Air Policy Commission (they became fast friends). In 1948 he was named special deputy to Secretary of Defense James Forrestal and prepared for him the first and second defense budgets of the newly-formed Department of Defense. In June 1950 President Truman called him back to be Undersecretary of the Air Force under Finletter; until October 1951, in that period of mobilization for Korea, McCone was primarily responsible for aircraft procurement and construction of air bases throughout the world. Production of military planes doubled during his 16 months as undersecretary.

NEW ARRIVAL on the atomic scene, John A. McCone is shown last month with his wife, the former Rosemary Cooper

While in that post McCone recommended a "czar" be placed over the guided-missile program, with "absolute power over the entire effort," and has since repeated that recommendation to President Eisenhower, whom he frequently visits at the White House for informal chats. He has also advised Defense Secretary Neil McElroy on defense reorganization.

Open-Minded Conservative

On development of economic nuclear power, one personal friend of McCone has been quoted as predicting he "will be to the right of Lewis Strauss," calls him "very definitely a conservative who believes in the capacity of private enterprise to deliver the goods." On the other hand Terence M. Lee, McCone's administrative assistant since early 1951 (and a good bet to follow him to Germantown), says McCone's preference for private business doing the job wherever it can "does not mean McCone would hesitate to have Government do the job if it would help get it done. In other words, whereas he prefers private business to 'creeping socialism,' he'll approach all matters with an open mind and wouldn't let his basic preference interfere with getting a job done."

Lee believes McCone's principal key to success is his razor-sharp intelligence that can pierce any proposal, reduce it to a skeleton of basics. Others among his West Coast associates describe him as "a warm, cordial personality, forthright and extremely frank," with "a gift for friendship," and a good sense of humor. He is well read, mainly in history and public affairs.

Entire Reactor High Command at AEC Changing Hands; Gen. Luedecke Will Be New General Manager in Fall

One of the most urgent tasks awaiting John McCone when he takes over the reins of AEC is an internal one: to plug the gaps left by the most massive group of key resignations in recent AEC history.

By the end of June the entire chain of command on civilian reactors had been wiped out by resignations: Kenneth E. Fields, general manager; Richard W. Cook, deputy general manager; W. Kenneth Davis, director of the division of reactor development; Louis H. Roddis, deputy director, and Clark Goodman, assistant director, all followed Strauss in leaving Germantown. They left the industry understandably worried as to the direction that would be followed by their successors, as well as to the continuity of direction during the interregnum while their successors, first, are recruited, and second, work into their jobs.

Cook will be employed in the executive offices of American Machine & Foundry Co. Davis will return to California as vice-president of Bechtel Corp. Roddis will be president of Pennsylvania Electric Co., Johnstown, Pa., a subsidiary of General Public Utilities Corp. Goodman will be vice-president of Schlumberger Ltd., stationed at its Ridgefield, Conn., research center. Fields has not told his plans.

Short-Term Remedies

To cope with the immediate situation, AEC named a new general manager—who, however, cannot assume his duties until after conclusion of the present series of weapons tests at Eniwetok which he is directing, probably not until end of September. He is Major General Alvin Roubal Luedecke, USAF, commander of Joint Task Force Seven, and as such the ranking military officer and AEC's principal official at the Eniwetok Proving Grounds.

To fill in, AEC named Assistant General Manager Paul F. Foster to serve as Acting General Manager from July 1, date of Fields' departure, until Luedecke's arrival. And in reactor development the search is on for successors to Davis, Roddis and Goodman; Davis' last day on the job is July 31, and an acting director will be named if the job has not been filled.

One persistent Washington story has it that the reactor development division may be split in two, with all propulsion programs—naval, maritime and aircraft—being lumped together in one division under Admiral Rickover, and central-station power reactor development comprising a separate administrative unit, under a chief yet to be chosen.

Luedecke's selection "was based upon his long and varied experience in the field of atomic energy and his outstanding technical and administrative ability," Chairman Strauss declared. Luedecke, who will resign from the Air Force upon taking office, has been in the atomic energy program since 1949; he served as executive secretary of the Military Liaison Committee, 1949–1951; deputy chief of the Armed Forces Special Weapons Project, 1951–1953; chief of AFSWP, 1953–1957; since then, commander of Joint Task Force Seven. Born in El Dorado, Texas, in 1910, he earned his B.S. in chemical engineering at Texas A. & M. in 1932; became a flying cadet, served as military attaché for air in Latin America. During the war he was first in Latin-American intelligence, later held various air staff posts in the China-Burma-India theater.

Foster came to AEC as special assistant to the General Manager in June 1954 from the World Bank. Previously a Chicago department store executive, he had been, in World War II, the first naval reserve officer to reach the rank of Vice Admiral.

Retiring Chairman Strauss, who will also hang up his second hat as personal atomic adviser to the President, will don a new one: special assistant to the President to promote the atoms-for-peace program. With an office in the White House rather than at Germantown, Strauss in his new post is expected to retain some of his influence in Presidential councils on atomic matters. However observers feel that McCone—even though he may have been, as has been reported, Strauss' personal choice to succeed him—is a man who will make his own, independent, decisions.

Long Term Remedies

The upper-echelon personnel problem that faces McCone is more basic than the filling of a few key posts, however. In its brief 11-year history, AEC—an organization with jurisdiction over territories larger than the State of Rhode Island, with only 6,800 direct employees but 100,000 working for its operating contractors—has enjoyed unusually high morale for a government agency, due in large part to the exciting and novel nature of its work. In recent years, however—and in spite of the great advances made in many fields—morale in AEC staff has deteriorated, to an extent that it is seen by many as a major factor in the recent resignations.

The principal cause for this state of affairs appears to have been the feeling of high-ranking program officials that they had little real authority or responsibility for the programs nominally under them, that their recommendations were discounted or even ignored at the Commission level, and thus that their influence on their programs was not what they felt it could and should be. Added to this was the fact that while AEC had been embroiled with the Joint Committee on one front, fighting against an accelerated long-term reactor program, at its rear the Bureau of the Budget was chopping out large segments of what program AEC did wish to undertake, with a consequent "atrocious" effect on morale of AEC's scientists and operating personnel (NU, Jan. '58, 17).

At the other end of official Washington, AEC's top staff officials had to endure sometimes merciless hectoring and badgering from JCAE members. Finally there was the unpopular move in January 28 miles out of Washington to the handsome but badly-laid-out new building in the green rolling pastures of Montgomery county, Maryland.

Organizational Review

As one of his last acts, Strauss confirmed that he had initiated "a comprehensive review" of AEC's organization, and that this had been in progress "for the past several months." Undertaken "to review the effectiveness of existing organization in the light of added and evolving duties of the Commission," it was carried out by "a small task force" under Assistant General Manager Harry S. Traynor and John G. Adams, attorney and consultant. The study, together with recommendations, was completed and filed in late April, but Strauss had asked that action by AEC on major recommendations be deferred until McCone takes office.

JCAE Votes Doubling of AEC's '59 Program

The Joint Committee on Atomic Energy, mounting its boldest offensive for acceleration of the U. S. Atomic energy program since the ill-fated Gore-Holifield bill of 1956, last month added almost $200-million in reactor and research projects to AEC's fiscal 1959 construction authorization bill. AEC had asked authority totalling only $193-million for fiscal '59, including $115-million for federal and private reactor development (NU, June '58, 18).

Subject to approval by both House and Senate, JCAE forced into the '59 program these major items:

- A $145-million plutonium production reactor that can be converted to production of electricity, as well.
- A $2.5-million design and engineering study of a large-scale reactor cooled and moderated by heavy water. The study must be presented to JCAE by April 1.
- A total of $6-million to finance engineering and design studies on three heavy-water reactors—two large-scale and one intermediate in size. Deadline is May 1.
- A $750,000 design-engineering study of an advanced boiling water reactor using nuclear superheat (already proposed to AEC by the Puerto Rican Water Resources Authority in a 15 Mw(e) size). Deadline for this study is April 1.
- Almost $40-million in research facilities chopped out of the program by AEC and the Budget Bureau. AEC had proposed $20-million in new research facilities but this was cut by Budget to $9-million. Another $175-million in research projects had been deferred by AEC.

JCAE also . . .

The Joint Committee also modified AEC's request for authority to proceed with the construction of a $51-million gas-cooled, slightly enriched, 40 Mw(e) reactor of advanced design; JCAE accepted AEC's proposal to canvass private industry on willingness to build the reactor but imposed a time limit of 30 days after the authorization bill becomes law for the canvass, and a limit of 60 days beyond that for AEC approval of any proposal that might be forthcoming.

In other significant moves on the authorization bill, JCAE:

- Extended the deadline for proposals under AEC's third round demonstration to June 30, 1959 (AEC had asked extension to December 31, 1959).
- Approved AEC's request for extension of the waiver of use charge on heavy water to any proposed reactor otherwise eligible for AEC assistance under the third round; the waiver is now limited to natural uranium reactors.
- Approved AEC's request for $20-million as a contingency fund for proposals which might be tendered under the third round but conditioned the approval in this manner: Before the authority can be used AEC must "make public announcement of each particular reactor project it considers technically desirable for construction and . . . set reasonable dates for 1. submission [of proposals]; 2. approval of the proposals as a basis for negotiation or arrangement; and 3. commencement of construction."

AEC Liberalizes Use of Non-Reactor U

AEC took two steps last month to broaden the commercial market for uranium: (a) removed the prohibitions in effect since World War II on the non-nuclear uses of U; and (b) opened its stocks of depleted U for sale on an unclassified basis to domestic and foreign users, subject to AEC's licensing procedures. Depleted U will be sold as UF_6 at this price range: minimum of $5/gm for UF_6 containing 0.36wt% U-235 or less; $38.15/gm at the maximum 0.7% U-235 content. The charges apply to both domestic and foreign sales.

AEC said removal of restrictions on non-nuclear uses of U would permit resumption of applications in the ceramics, glass, coloring and photography industries, among others, which used some 200 tons/yr before 1940.

Cordiner Proposes Meeting on U. S. Atomic Policies

Ralph J. Cordiner, board chairman of General Electric, last month invited executives of other reactor manufacturers and of private utilities to meet at Woodside, Calif., late in September "for a thorough exchange of ideas on the nation's atomic energy policy." The invitation is tentative, awaiting industry's reaction. Cordiner said it was inspired by his feeling that Congress "will undoubtedly rewrite" the 1954 Atomic Energy Act next year.

Inadvertent Criticality At Oak Ridge Hurt 8

That dreaded nuclear accident—an inadvertent accumulation of a critical mass of fissionable material—occurred for the second time in AEC history at 2 p.m. June 16 in an enriched-U scrap recovery building at Oak Ridge's Y-12 plant. In an unidentified chemical processing operation for U^{235}, enriched U in solution was being emptied directly from a small-diameter container into a drum when the material in the drum became critical. There was no explosion; automatic radiation monitors were triggered and sounded the alarm.

Eight production-workers received exposures ranging from 20 to 320 rad; three were discharged after ten days observation, the other five are reported "resting comfortably" but will remain hospitalized at the Medical Division of Oak Ridge Institute of Nuclear Studies for perhaps another fortnight. They exhibited "slight depression of the blood-forming tissue" and "some nausea" immediately after the accident but "no progression of symptoms" since, are receiving no new methods of treatment for radiation exposure. Four top U. S. specialists in radiation medicine went to Oak Ridge and spent a week observing the patients.

This was the most serious radiation exposure in this country since two cases of inadvertent criticality in pre-AEC Manhattan District days at Los Alamos (August 1945 and May 1946), in each of which one man died—only fatalities in the U. S. atomic program. The only other case of inadvertent criticality occurred in Chicago June 2, 1952, during control-rod tests on an experimental reactor; highest exposure then (of four men exposed) was 176 rad.

Atom-Sharing Bill Passed by Congress

Congress passed and sent to the White House a bill permitting the U. S. to share nuclear materials and military secrets with friendly nations. Aside from its weapons aspects, the measure allows transfer of information reactor designs and fuels for submarine and other military power plants. France—which recently halted work on Q-244, her natural-uranium-powered submarine, to study enriched propulsion reactors—stands to get a nuclear sub under the act.

Industry, AEC Finishing Exhibits for Two Geneva Shows; Mammoth Conference Already Dwarfing 1955 Meeting

With less than two months left to go before Aug. 31 when the two nuclear exhibits at Geneva open their doors, AEC and industry exhibitors are straining to meet the short deadlines for completion of displays.

The U. S. will dominate the governmental exhibit, to be held this year in a huge, specially-erected temporary hall (*see photo*). Of its 75,600 sq ft, AEC has asked for 36,720. Russia will have 10,800 sq ft, France 6,480, Britain 5,400, and smaller areas will be used by Canada, India, Sweden, Norway, Denmark, Italy, West Germany, Venezuela, Switzerland, Czechoslovakia, Hungary, Japan, Belgium, Australia, Spain, South Africa and Argentina.

Here AEC will show "a fifty-part general technical exhibit . . . [that] will encompass the whole range of peaceful uses" of the atom. In addition to Argonaut and Triga research reactors (NU, May '58, 21), there will be at least seven working devices demonstrating as many experimental approaches to harnessing thermonuclear power: a model Stellarator from Princeton, a DCX from Oak Ridge, a mirror machine from Livermore, and four exhibits, two of them neutron-producing, from Los Alamos.

The U. S. displays alone will require 3 Mw(e) of current (2 Mw for the fusion machines), and a temporary pipeline reaching down to Lake Geneva, at the foot of the hill below the exhibit hall, is being built to supply 800 gpm water for cooling. There will also be a full-scale model of the 38-ft-high of the Shippingport PWR pressure vessel and core; and three operating laboratories: a health and safety lab, a radiochemistry and isotope lab, and a carbon-14 labeling demonstration.

The U. S. is also preparing 45 technical films to be shown at Geneva—and to be available in English, French, Spanish and Russian versions. Seventeen "feature" films (30–45 min) will be shown at the Palais des Nations. They will deal with U. S. power reactors, U. S. research reactors, reactor safety experiments, reactor fuel processing, the fast reactor program, SRE, OMRE, EBWR, PWR, HRE-2, ETR, Argonaut, the medical research reactor; also fusion research, high-energy accelerators, teletherapy and brachytherapy, and non-root feeding of plants. The other 28 films, "shorts" of 5–15 min, will be shown in a special, four-compartment theater in the exhibit hall.

As compared with 21 nations and 75,600 sq ft in the governmental exhibits, the commercial show—held again this year in the downtown Palais des Expositions—will see firms from 12 nations using 115,230 sq ft of display space. Here U. K. and French industry lead the U. S. in the space race with 31,000 and 29,000 sq ft as against 23,000, followed by Switzerland 8,500; West Germany 5,300; Italy 2,120; Netherlands 1,060; Liechtenstein 1,060; Belgium 530; Hungary 320; Sweden 270; Austria 270. Russia hasn't exercised its option on 10,600.

Forty-nine U. S. firms plus AEC will exhibit at this show, largest commercial display of atomic products and services yet held anywhere. Two more working U. S. reactors will be shown here—an Atomic International L-77 lab reactor, and an Aerojet General-Nucleonics AGN-201. Focal point of the U. S. section will be a full-scale model of the core of a 150-Mw(e) reactor. Tying together the various U. S. displays, the AEC exhibit will have as themes the partnership between U. S. private enterprise and government, and the power reactor fuel cycle. Other features of the U. S. section will be an information center (there will also be one at the governmental exhibit), a mobile isotope lab, and a small movie theater showing both AEC and industry films.

If those who attended the first Geneva conference on Peaceful Uses of Atomic Energy in 1955 thought that was a monster affair, they will find at Geneva-II that, even seeing, it is difficult to believe. As a matter of fact, U. N. officials believe this year's meeting, certainly the biggest ever held under U. N. auspices, may well be the biggest formal international conference ever held. No fewer than 5,000 are expected to attend, as compared with 3,000 in 1955. Britain will send 280 in its official delegation and 250 observers, the U. S. 200 advisers and 350 observers, France 150 advisers and 100 observers. Russia is sending 150, India 50, Canada 50.

The 21 nations bringing governmental exhibits this year compare with nine in 1955; their 75,600 sq ft of display space compares with 17,280. The number of papers submitted has grown from 1,070 to 2,409; the number of countries submitting them from 38 to 49; the average length of each paper from 15 to 21 pages; the number of parallel series of technical sessions from three to five; the total number of sessions from 55 to 77; the number of volumes required to contain the proceedings from 16 to 33. The total flood of paper used before the conference even begins, just to print the abstracts and papers, will comprise 220,000,000 pages—550 tons!

TEMPORARY EXHIBIT HALL for governmental displays is rising on slope below Palais des Nations, Geneva. Rectangular building will be 548 x 164 ft, with 40-ft high bay, center, and 18-ft low bay, right edge. Peter Steiger of Zürich is architect, Etablissements Casai et Cie. of Geneva is builder. Pipes in foreground will bring lake water to cool U. S. fusion exhibits.

Euratom Bill on Hill; Fuel Cycle Terms Set

The first link of the U. S.-Euratom agreement finally went up to Capitol Hill from the White House on June 23—and prognostications were rather glum as to whether this was in time for Congressional approval of the program before adjournment, required if the program is to get under way this year. This first link is no more than a very short, three-article door-opener, an agreement to agree, between U. S. and Euratom, required by Sec 123 of the 1954 Act. It paves the way for the bilateral treaty that will spell out the details of the U. S. aid program. In asking for approval "on an urgent basis" of this first step, the President told Congress "the necessary requests for Congressional action required to carry out the program will be submitted shortly."

Whether this would be soon enough was the question that had the U. S. atomic industry holding its breath last month. Plans were to seek a waiver of the 30-day waiting period before JCAE for the bilateral, which must be okayed by Congress before European utilities and U. S. manufacturers can realistically start doing business. The mood of the Joint Committee on Atomic Energy appeared to be one of real sympathy for aid to Euratom and understanding for the vital need of U. S. industry to be able to sell to it, but combined with a refusal to be rushed into approving details of any arrangement without examining them closely.

Rep. Chet Holifield (D-Calif.) of JCAE told NUCLEONICS, "I doubt if there will be any agreement this year, unless there's an unusual display of harmony and of ability [by AEC] to sell the program to the Committee." And Sen. Clinton P. Anderson (D-N. M.), who stands to resume JCAE's chairmanship in January, went far out of his way in his New York talk to the Nuclear Energy Writers Association to dwell on the imperative need for the U. S. to help other energy-short peoples by exporting economic reactors; yet in the same talk he indicated opposition to what he called the "no down-payment" feature of the proposed financial aid to Euratom, as being "a poor way to do business," and said he would want to take "a long look" at it.

Meanwhile industry was studying the terms of the fuel cycle guarantees envisioned in the U. S.-Euratom aid arrangements, as outlined in the "memorandum of understanding" that contains the principles to be spelled out in legal language in the bilateral (NU, April '58, 19; June '58, 17).

The objective of the fuel cycle program is that arrangements for supplying fuel elements for the million-kw cooperative program will meet either one of the following two criteria:

1. The integrity of the stainless steel or zirconium clad fuel elements for light-water-cooled and -moderated reactors is guaranteed to an average irradiation level of 10,000 MWD/metric ton of contained uranium, and the charge for fabrication of fuel elements starting with UF_6 is (a) $100/kg of contained U for fuel elements of UO_2 having a U^{235} concentration no greater than 3% by weight, 0.25–0.50 in. dia, and stainless steel cladding; or (b) $140/kg of contained U for similar elements, Zr-clad; or (c) appropriately adjusted charges for other types of elements.

2. The irradiation level in the integrity guarantee and the fabrication charge for fuel elements differ from the values specified above, but the combination gives a computed fuel-cycle cost equal to or less than the standard fuel cycle cost.

AEC Guarantee

Arrangements for supplying fuel elements under one of these two criteria may be made with commercial sources, but it is foreseen that in the event of fuel-element failure, such arrangements may not cover the extra costs of reprocessing and transporting irradiated elements to meet the standard fuel-cycle cost. In such cases, AEC will, for the purpose of prorating the reprocessing and/or transportation costs, offer to guarantee an average irradiation level, which, in combination with the manufacturer's guarantees, would result in a computed fuel-cycle cost equal to the standard fuel-cycle cost. If the average irradiation level guaranteed by AEC is exceeded, half the resultant savings in reprocessing and transportation costs is to be credited to AEC.

"Fuel element guarantees may also be developed," the memorandum states, "for proven types of reactors other than light-water-cooled and -moderated, determined by the Euratom Commission and AEC to be eligible for consideration under the joint program."

Other Highlights

- Total capital cost (excluding fuel inventory) of the million-kw(e) of reactor plants covered is estimated at not more than $350-million, of which ~$215-million is to be provided by the participating utilities and other European sources of capital, and up to $135-million is to be provided by the U. S. as a long-term line of credit, the funds to be re-lent by Euratom for construction of facilities.
- AEC is prepared to provide reprocessing, at U. S. domestic prices, and in addition agrees to assist the O.E.E.C.-sponsored "Eurochemic" syndicate (NU, Jan. '58, 22) in building its pilot reprocessing plant.
- The joint research and development program on proven types of reactors and on plutonium recycling "and other problems relevant to these reactors" is set up for 10 years. During the first five, Euratom and the U. S. will each contribute $50-million to it, then determine costs for the second half. Information developed under this program would be made available currently to the two parties for use or publication without obligation; patentable information would be shared, in non-exclusive royalty-free patents.
- The U. S. would sell Euratom 30,000 kg net of contained U^{235} to cover fueling and other needs of the program for 20 years. The initial operating inventory, amounting to ~9,000 kg, would be sold on a deferred-payment basis; the balance—~20,000 kg representing burnup and process losses over 20 years, and 1,000 kg for research and test reactors needed in the program—would be paid for on a current basis.
- Plutonium produced in U. S.-supplied fuel in Euratom reactors exceeding Euratom's peacetime needs could be bought, under first option, by the International Atomic Energy Agency, at prevailing U. S. prices. AEC is prepared to buy back the Pu during the first 10 years of reactor operation should IAEA not exercise its option.
- Euratom will seek to develop and, by the earliest practicable date, secure adoption of provisions for adequate financial protection against third-party liability.
- Euratom will establish and operate, with U. S. agreement and aid, a safeguards and control system against diversion of fissionable material to weapons uses. The system is to be "reasonably compatible" with IAEA's control system.

Reactor News

ARBOR ABORTED

Arbor, the 200-Mw(th) boiling reactor test facility Argonne was planning to build in Idaho (NU, Jan. '57, R8), is no more. It was thrown out of AEC's appropriation requests by the Budget Bureau for the second year running. "As far as Argonne is concerned, the project is dead," a top ANL official told NUCLEONICS; "we're not going to push it any further." The Arbor staff has been set to work on problems of superheat common to boiling reactors—"something we've been wanting to do for a long time."

CONSTRUCTION RESUMED ON NPD

Work at the site of Canada's first nuclear power station, NPD, is to be resumed this month after a year's interruption to permit technological advances to be incorporated in reactor design (NU, June '57, 26; Feb. '58, 25). Instead of the usual vertical pressure tank, the core will be a horizontal aluminum tank 13 ft long, 15 ft dia, containing 132 aluminum tubes in which are zircaloy pressure tubes that in turn contain the fuel elements and D_2O coolant. Remotely-operated charging machines at each end of the vessel will permit loading and unloading of fuel from both ends while at full power. The 20-Mw(e) plant is to be completed in 1961, and will serve as pilot plant for a 200-Mw(e) station now being designed in Toronto by the new Nuclear Power Plant division of Atomic Energy of Canada Ltd.

WTR CORE TESTED CRITICALLY

Westinghouse's big nuclear research center at Waltz Mill, Pa., passed another milestone when the core for the Westinghouse Testing Reactor first went critical at 10 watts in a test installation in the Critical Experiment Station (one of two criticals in the Westinghouse Reactor Evaluation Center at Waltz Mill; the other, CRX, has been operating—on Yankee core design problems—since last Christmas: NU, Feb. '58, 26). WTR itself is rising rapidly 500 ft from WREC on the 850-acre site; the core will be transferred from CES early next year for 20-Mw(th) operation (at 1.2×10^{14} peak thermal flux). WTR is to be ready for operation in spring 1959, will cost ~$4-million; Westinghouse's total investment at Waltz Mill is expected to reach $12-million.

DESTROYER REACTOR CONTRACT TO KAPL

Knolls Atomic Power Laboratory was awarded an $11.93-million Navy contract to supply long-lead-time reactor-compartment components for the first guided-missile-firing nuclear-powered destroyer, including twin reactor vessels, steam generators, coolant pumps, and valves. A land-based prototype, D1G, is being built by GE inside the 225-ft sphere at West Milton, N. Y., that housed the prototype S1G sodium reactor for *Seawolf* (NU, April '57, 24; Aug. '57, 22). Ebasco is architect-engineer for required modifications and additions to the sphere and adjoining facilities.

NEW REACTORS

Michigan Chemical Corp. of St. Louis, Mich., has notified the Joint Committee it is interested in building a small process-steam reactor and is preparing a proposal to submit to AEC. The firm makes chemicals for pharmaceutical, industrial, agricultural and insecticide uses, utilizing the many brine deposits nearby for raw material. . . . The Army's Watertown (Mass.) Arsenal research reactor (NU, April '58, 25) will be built by Curtiss-Wright's Research division. Vara Construction Co. is prime contractor. . . . As expected, the order for APPR-1a being built at Ft. Greely near Fairbanks, Alaska, went to Alco Products, builder of the first Army Package Power Reactor and designer of the modified version for field use. Basic design is the same as in the 10-Mw(th) APPR-1 at Ft. Belvoir, Va., but the Alaskan model will have twice the heat output from the same size core, and its primary components (other than core) will be larger. Half the thermal output will be used to make electricity, the other half for space heating. Initial work is underway, and APPR-1a is to start furnishing all the current used at Ft. Greely in 1960. . . . "Susie," a swimming-pool reactor to serve as shield test facility for nuclear airplane work at the Idaho reactor test center, is being designed and built by Bendix Aviation Corp.'s Research Laboratories division. . . . Argonne expects to complete TREAT (Transient Reactor Test facility) at Idaho this year. The $1-million facility (NU, March '58, 25) will deliver short-duration, high-intensity pulses of neutrons, generating intense heat in samples under test such as prototype fuel elements, thereby simulating nuclear-excursion conditions. Great Lakes Carbon Co., entering the fuel field, is making TREAT's fuel pellets of uranium oxide dispersed in graphite; these will be clad in aluminum by Argonne. . . . AEC and ACF Industries have signed a contract for construction of the Elk River boiling reactor. Agreement on the "basis for contractual arrangements" was announced last month (NU, June '58, 25). . . . Senator Gore (D-Tenn.) of JCAE called for a 50–100-Mw(e) aqueous homogeneous reactor to be built at Oak Ridge.

KEWB UNDERGOES RECORD TRANSIENT

KEWB (Kinetic Experiment on Water Boilers) has increased its power output from 0 to 530 Mw(th) in less than a second and shut itself off without sustaining any damage. This rate of power increase is the largest known to have been experienced safely by a reactor, according to KEWB's builder, Atomics International.

KIWI-A, ROVER TEST, COMPLETED

Kiwi-A, an experimental reactor for Project Rover (Los Alamos' nuclear rocket propulsion project) has been completed and is being assembled at the Jackass Flats, Nev., Rover test site (*see p. 69*) where it will be tested late this year in initial static ground experiments. Reactor shell and support equipment for Kiwi-A (named for the flightless New Zealand bird) were built at the South Albuquerque, N. M., works operated for AEC by ACF Industries.

DIRECT CONVERSION AT GENERAL ATOMIC?

Already out in the front lines of power research with its privately-financed fusion study (NU, June '57, 17), General Atomic division of General Dynamics last month tackled direct conversion of heat into electricity. This is part of a two-year, $500,000 research effort GA will undertake for eight investor-owned utilities to be known as the Rocky Mountain–Pacific Nuclear Research Group.* The two-pronged program covers "conception and development of fission reactors capable of producing the high temperatures and pressures required for modern power plant operation," with major emphasis on gas-cooled reactors, as well as thermoelectric generation from nuclear fission heat. Also known to be working on thermoelectricity for at least a year are Westinghouse (for the Navy) and General Electric.

* Arizona Public Service Co.; California Electric Power Co.; Pacific Power & Light Co.; Portland General Electric Co.; Public Service Co. of Colorado; Public Service Co. of New Mexico; Utah Power & Light Co.; Washington Water Power Co.

ROUNDUP

World News

RWE Reactor Ordered; GE Gets Share

RWE (Rheinisch-Westfälisches Elektrizitätswerk AG of Essen, West Germany's biggest utility) has finally reordered its long-planned 15-Mw(e) boiling reactor on which an earlier deal with Mitchell Engineering and AMF Atomics fell through (NU, March '58, 26; June '58, 26). The order goes to Allgemeine Elektrizitätsgesellschaft, (German for "General Electric Co."), which has a cooperation agreement with American GE. AEG will build the plant in cooperation with GE and the Essen construction firm Hochtief AG of which AEG owns 34%. Value of the order is placed in the range of $8-million. It will be built at the site selected for the AMF reactor, at Kahl am Main, 13 mi east of Frankfurt. RWE still plans to build a 250-Mw(e) nuclear station but has found no suitable offer so far, RWE director Heinrich Schöller said. The utility has been negotiating for a year with a group of four British firms, but the offer promised by the latter has been repeatedly postponed.

U. K. A-Station at Cross-Channel Link; French Pick Site

The next British nuclear power station will connect with the French electricity system through the projected cross-Channel power cable. The site chosen is at Dungeness, Kent, in the southeastern corner of England opposite Boulogne, France and astride the long-sought 275,000-volt Anglo-French interconnection. The station would have a capacity of 500–550 Mw(e). Dungeness will be the sixth British nuclear station: Bradwell, Berkeley and Hinkley Point in England and Hunterston in Scotland are under construction (NU, June '58, 23), and a fifth has been proposed for Trawsfynydd in Wales (NU, Sept. '57, 31). Permission to build at Dungeness is being sought by the Central Electricity Generating Board. . . . Electricité de France has picked a site on the Meuse river in the Ardennes, near Belgium, for its 150-Mw(e) plant EDF-3.

Japan Signs Bilaterals with U. S., Britain

Ten-year agreements for cooperation in the nuclear field were signed June 16 by Japan's ambassadors to Britain and the U. S. in London and in Washington. The U. S. pact provides for supply of 2,700 kg of U^{235} for power reactors in Japan. The British bilateral covers construction of a 140-Mw(e), $84-million Calder-type power plant with earthquake-proofing modifications on which the Japanese are seeking bids from four British consortia. It also provides for purchase in Britain of research reactors and nuclear fuel, exchange of unclassified technical information, use of British training facilities and British assistance on construction of nuclear power plants.

Twelve Countries to Operate Halden Reactor

Norway's Halden reactor, the world's first boiling heavy-water reactor and first process-steam reactor, will be operated jointly by 12 European countries under the auspices of OEEC's European Nuclear Energy Agency (NU, Jan. '58, 21, 22). An agreement covering the arrangement for a three-year period beginning July 1 was signed in Paris last month by the six Euratom countries, Austria, Britain, Denmark, Norway, Sweden and Switzerland. U. S. collaboration has been offered to the group. The agreement provides a budget of $4-million for a research program in boiling reactor problems. The Norwegian Institute for Atomic Energy, which built and owns the reactor, will carry out the program with a staff recruited from the 12 countries. The Halden reactor, 75 mi south of Oslo, is now expected to go critical in September.

Britain Expands Fuel Element Capability

Britain's Atomic Energy Authority has launched two projects for speeding up output of fuel elements. One is an extensive new plant, now under construction at Springfields (Britain's Fernald), for converting U ore into metal fuel elements. The other is scheduled enlargement of the chemical separation plant at Windscale (the English Hanford) to provide a central fuel-element processing facility for the entire nuclear power program. AEA declined to give further details about either plant. But Sir John Cockcroft, who made the announcement, said the two programs would permit big economies in the supply and processing of Calder-type elements for the early civil stations, as well as similar ones exported. Export fuel elements would carry a maximum price of $56,000/metric ton; Britain would buy back spent elements at a minimum of $14,000/metric ton for their plutonium content, valued at $14/gm. Sir John also announced that the Calder Hall station will carry out experiments on behavior of fuel elements at higher heat ratings; this will be achieved by inserting batches of elements containing enriched U.

Italy, Japan Envisioning Nuclear Ships

Fiat of Turin and Ansaldo of Genoa, Italy's biggest auto builder and shipbuilder respectively, have started work on a joint project to build a power plant for a 70,000-ton nuclear tanker. The engine would supply 32,000 hp, driving at 18 knots a tanker 765 ft long, 107-ft beam, 68,800 displacement under full load. . . . Japan has submitted two papers for the Geneva conference dealing with plans for a 20,000-ton, 23-knot nuclear passenger ship and a 30,000-ton, 22-knot submarine tanker.

Internuclear Gets Study Job in Spain

Centrales Nucleares del Norte (Nuclenor) of Spain has engaged Internuclear Co., Clayton, Mo., to conduct preliminary studies on building of a 200-250-Mw(e) nuclear power plant in northern Spain. Site selection studies are already being carried out by Internuclear.

Canada Sets Up Nuclear Insurance Group

Following the U. S. lead, Canada's insurance firms have formed a pool to handle nuclear risks. Nine fire and casualty firms founded the Nuclear Insurance Association of Canada; its first aim will be to set up a $10-million fund to meet possible claims. Nearly all Dominion-licensed fire and casualty firms in Canada are taking part.

Thailand to Buy U. S. Research Reactor

Thailand will buy a U. S. swimming-pool reactor to get its nuclear program under way. Boonrod Binson, secretary-general of the Thai National Energy Authority, said the Cabinet had accepted a U. S. proposal to contribute half the cost of a research unit under the Atoms-for-Peace program. Facilities of the reactor—to be erected on the grounds of Chulalongkorn Univ. in Bangkok—will be available to other Thai universities as well as to scientists from neighboring Cambodia and Laos.

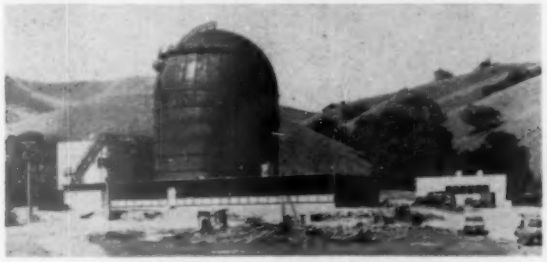
News in Brief

Air Force to Build ANP Facility in Denver

A $65-million research and development facility will be built by the Air Force as part of the effort to perfect a nuclear airplane. The installation, to be located near Denver's municipal airport, will employ 3,000, including 1,200 scientists and technicians. It will be devoted solely to development of nuclear propulsion units. Construction is scheduled to start late this summer for completion in three years.

Second Dome for Vallecitos

General Electric's $4-million testing reactor, GETR, is rising swiftly at Vallecitos, near the GE boiling water reactor and housed in a similar dome (*see photo*). The



30-Mw(th) GETR is to start up late this year; irradiation space will be commercially available.

JCAE Puts Off Waste Hearings

The Joint Committee's planned exhaustive study of the waste disposal problem, originally set for this spring, has been postponed to January 1959. On the other hand JCAE Chairman Durham told NUCLEONICS he hoped to hold hearings this year on effects of radiation "to see if we've learned anything since last year" when JCAE held thorough hearings on fallout effects.

Brush Gets Big Beryllium Job

Belgium's Centre d'Etudes de l'Energie Nucléaire, operator of the Mol research center where Belgium's first three reactors are built or building, has ordered two beryllium core matrices from Brush Beryllium Corp. for BR-2, the high-flux materials and engineering test reactor. The $1.2-million contract is the largest ever made for fabricated beryllium metal.

Military Reactor Unit Created at NRTS

A division of military reactors has been established at AEC's National Reactor Testing Station, Idaho, to coordinate the "varied and complex" military reactor and chemical processing programs. The division will be headed by V. V. Hendrix, director of reactor engineering at Schenectady Operations Office.

CEM Group, A. D. Little Win Radiation Contract

Emerson Radio, acting for the CEM Group, has been awarded an $86,847 AEC contract to conduct a study of industrial applications of high-level radiation (NU, Apr. '58, 24). Subcontractor on the technical aspects of the study will be Arthur D. Little, Inc., which is conducting a broad study of radiation application for Hanford. It is understood that Little's contract was a major factor in CEM's ability to underbid 22 other bidders for this contract. CEM (chemicals, electronics, metallurgy) includes Emerson, General Aniline & Film, and Revere Copper & Brass (NU, Aug. '57, 28). The 10-month study will be three-phase: 1. a review of world technology on current and likely uses of high-level gamma radiation sources; 2. a survey of industry's current and planned uses; and 3. a comparison of high-level radiation's potential with competitive energy sources.

First Atom Excavation in Alaska

AEC is studying the first explosion of a nuclear bomb for peaceful purposes—excavation of a harbor in northeast Alaska. U. S. survey parties under Project Plowshare will visit the proposed site this summer for data on cost, topography, geology, oceanography and possible effects on the area. If found practicable and safe, "the excavation could take place in 1960." Meanwhile AEC is still struggling to decide how to deal with the proposals of eight firms for a cooperative effort to put nuclear weapons to other peaceful uses (NU, Apr. '58, 21).

AEC Moves Ahead with Hi-Fi Negotiations

AEC's Office of Industrial Development, was near the end of negotiations last month on a contract to design, construct and test operate Hi-Fi, the 2-million curie, cobalt-60 gamma food irradiator to be built at Lathrop, Calif., for the Army Quartermaster Corps (NU, May, '58, 28). At the end of June, AEC picked Curtiss-Wright, one of 15 who bid, to build the $2-million facility.

AEC Shifts Boron-10 Distribution to Chicago

Under a revised plan for commercial distribution of boron-10 materials, AEC has shifted its distribution center from Niagara Falls to the Chicago Operations Office, effective July 1. The change follows shutdown of the enriched boron production plant at Niagara Falls; Michigan Chemical Corps. will store, pack and ship B^{10} materials under contract with the Chicago office.

Lockheed Begins Operations at Georgia Labs

The Georgia Nuclear Laboratories of Lockheed Aircraft were officially opened early last month when the installation's critical assembly went into operation. A 10-Mw test reactor is expected to be ready this fall. The Georgia facility was built for work on the Air Force's nuclear aircraft project, but an AF decision against an early goal for the project forced Lockheed to turn to commercial heat reactors to supplement airplane work.

Control-Rod Award to GE Likely

General Electric was the odds-on choice last month to get the prime AEC contract for a research-development program on new reactor control-rod materials (NU, Apr. '58, 25). AEC hoped to award the contract late in June. Over a period of several years, GE would conduct an initial survey, select materials, fabricate, then conduct preliminary and long-term performance tests (1–3 years). GE's bid was one of 22, AEC said.

AEC Field Offices to Issue Access Permits

Effective July 1, AEC's field offices have taken over responsibility for processing and issuing access permits. Heretofore they were issued in Washington and administered by the field offices.

Colombia Seeking U. S. Research Reactor

The Instituto Colombiano de Asuntos Nucleares of Bogotá has invited bids from a number of U. S. manufacturers for a research-training reactor, NUCLEONICS learns.

LATE NEWS SHORTS

NYC to Screen Film Badges

New York City's Department of Health will test and calibrate sample film badges of all commercial film-badge services, and after evaluation will offer a list of "approved" services to users under the City's radiation code. The list is to be kept up-to-date by subsequent spot-checking. All known services are being invited to submit samples; any others who wish to participate may contact the Office of Radiation Hygiene, 125 Worth St., NYC 13.

AMF Gets Puerto Rico Job

AMF Atomics snagged another swimming-pool contract: the $1-million, 7-Mw reactor for the $3.5-million Puerto Rico Nuclear Center at Mayagüez (NU, Nov. '57, 26). Southern Construction Co., Augusta, Ga., got a $1.27-million contract for the reactor building and lab. Meanwhile the Puerto Rico Water Resources Authority resubmitted its proposal to AEC for an $11-million, 15-Mw(e) boiling water reactor with nuclear superheat.

U. S. Atom Icebreaker Pushed

The House passed and sent to the Senate a bill for construction of a $40–60-million nuclear icebreaker.

National Lead: Fuel Elements

Nuclear Metals division of National Lead Co. is equipping its Albany, N. Y., plant to make plate, rod, pin—metal and ceramic—fuel elements, will start production in three months. The firm, which operates AEC's Fernald feed materials center, has been making fuel elements at Indianapolis for some time, is moving its equipment to Albany.

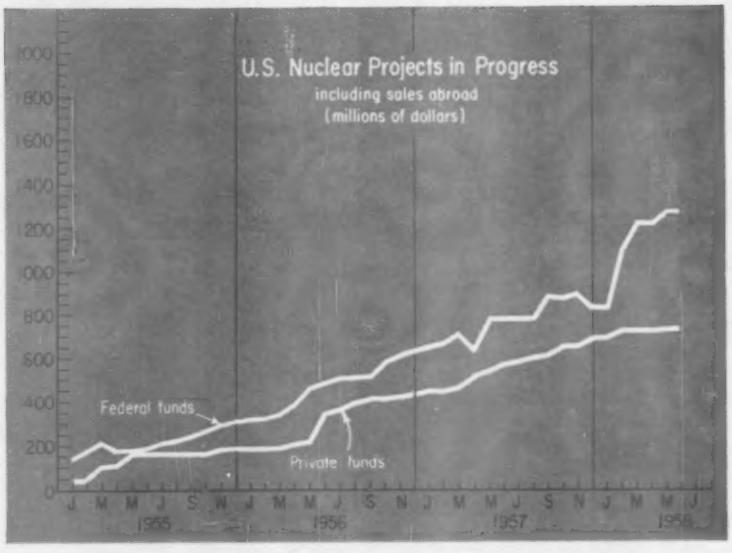
Startup in Poland, Red China . . .

The Russian-supplied D_2O pool-type research reactors at Swierk, 20 mi north of Warsaw (NU, Sept. '57, 24), and at Peiping went critical last month. The 2-Mw(th) Polish reactor, called "Eva," is identical to ones already operating in Czechoslovakia, Rumania and East Germany; the 7–10-Mw Chinese unit is like the one completed a month earlier in Yugoslavia.

. . . and Horace of England

A zero-energy pool reactor, "Horace," has been started up at Britain's atomic weapons establishment at Aldermaston, will be used to investigate different core arrangements and reflector materials.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for federal projects ($10³)	7,418	2,842	2,402
Proposed construction, privately-owned ($10³)	0	0	550
Contracts awarded, private work ($10³)	0	13,660	17,000
Backlog of private projects ($10⁶)	249	268	210
Access Permits †—			
Access permits issued	14	16	36
Total access permit holders	1,410	1,411	1,312
Isotope Use †—			
Applications for isotope use	578	629	537
Cumulative total of isotope users	3,750	3,692	4,041
Oak Ridge National Laboratory shipments	1,306	1,267	1,190
Public and private export shipments	238	426	65
Employment †—			
AEC employment	6,905	6,881	6,647
Construction and design contractors' employment	10,265	10,059	14,910
Total operating contractors' employment	113,355	100,777	97,098
Production workers	51,848	50,703	50,515
Research and development employees	44,760	43,791	39,873
Miscellaneous workers	6,482	6,871	6,701

	Operating	Building	Contracted
U. S.-built Reactors ‡—			
Power, domestic	1	5	9
Power, for export	0	1	2
Power experiments and pilot plants	7	4	1
Military and naval	5	22	11
Research and test, domestic	44	23	39
Research and test, for export	7	14	6
Foreign-built Reactors ‡—			
Power, domestic	4	24	12
Power, for export	0	0	2
Research and test, domestic	28	14	8
Research and test, for export	5	7	1

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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Our customers not only helped us develop the RCL 256 but also this ad—much of which is composed of excerpts from our survey of current RCL 256 users.

The improved

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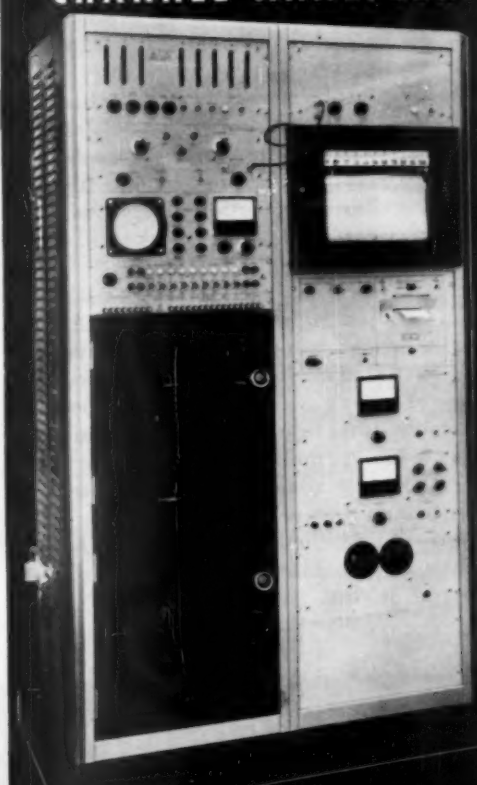

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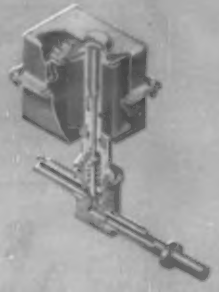
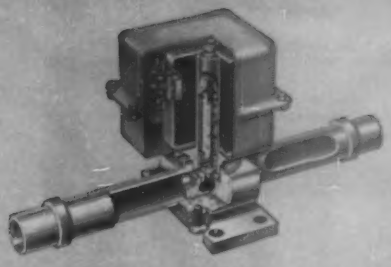
A few typical Solenoid Valves supplied for the primary system are illustrated here





STOP VALVE — For Coolant Purification System — shuts off circulating flow when temperature exceeds a predetermined value. Suitable for pressures to 2500 P.S.I. at 550° F, the valve will open against 125 P.S.I. differential pressure — others are available to open against 2500 P.S.I. differential pressures. Normally closed (valve fails closed). Supplied in 1" size, all stainless steel construction with stellite seats and discs.

PRESSURE OPERATED 4 WAY VALVE — Controls main cylinder operated Stop Valve in Circulating Loop. Valve is pressure operated requiring a separate source of air of 400 P.S.I. Equipped with manual operating handle and position indicator, valve has beveled, poppet type seats and discs for exceptionally tight seating. It is suitable for handling water at 3000 P.S.I. and 550° F. Has all stainless steel construction and stellite trim.

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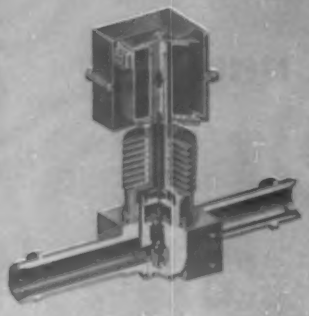

RELIEF VALVE—For water and steam — valve is electrically operated, controlled by pressure sensing device to relieve excess pressure. Normally closed (valve fails closed). Suitable for pressures to 2500 P.S.I. at 700° F. Available in 2" and 3" sizes. Body materials are monel, stainless steel and carbon steel with stellite seats and discs.

4 WAY VALVE—Controls main cylinder operated Stop Valve in Circulating Loop. Valve is solenoid pilot controlled and has beveled, poppet type seats and discs — for exceptionally tight seating. Supplied with manual override. It is suitable for 2500 P.S.I. differential pressure at 600° F. Supplied in 1" size, all stainless steel construction and stellite seats and discs.

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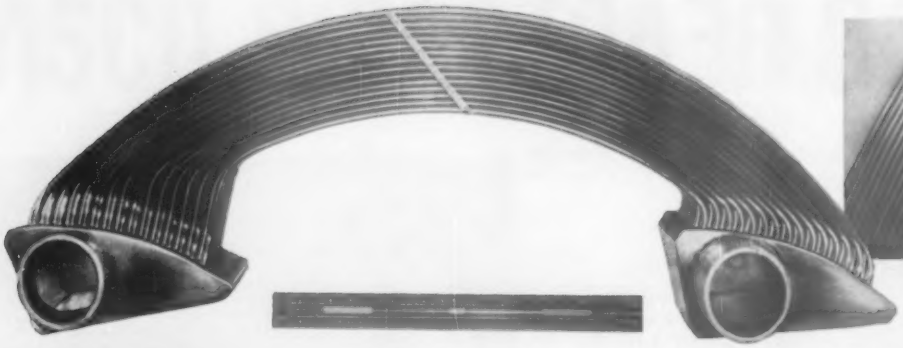
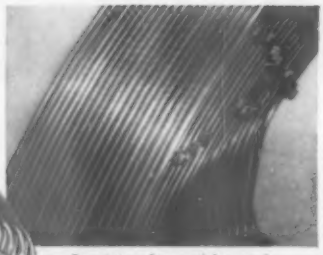
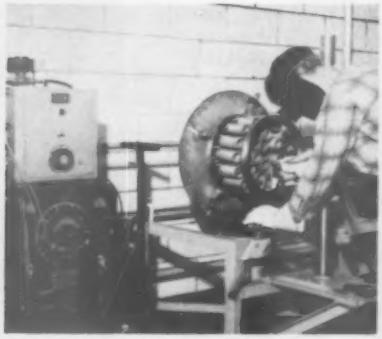




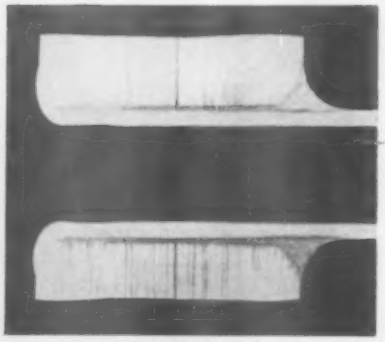
Precision formed Inconel Heat Exchanger plus detailed view of bends.

Precision welding

Welded tube joints



Automatic welding



Detail of tube joint

Photograph of G-R's brazing furnace facilities

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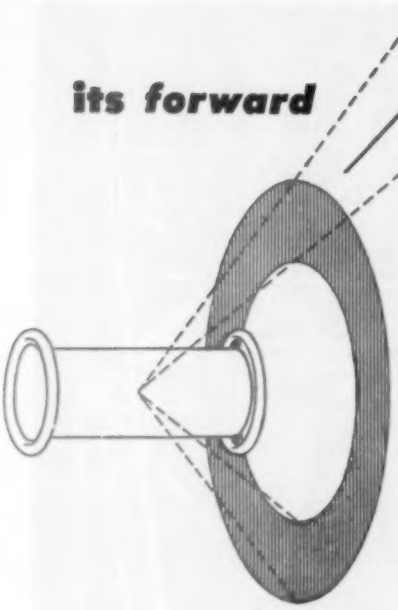
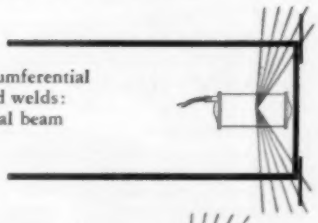
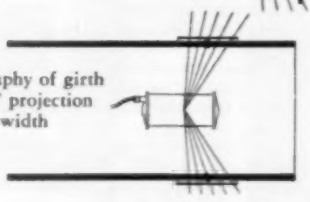


Inside-out one shot circumferential radiography of tank-head welds: the forward-thrown radial beam gets the whole corner.



Circumferential radiography of girth welds: the wide-band 30° projection x-rays the full seam with width to spare on either side.



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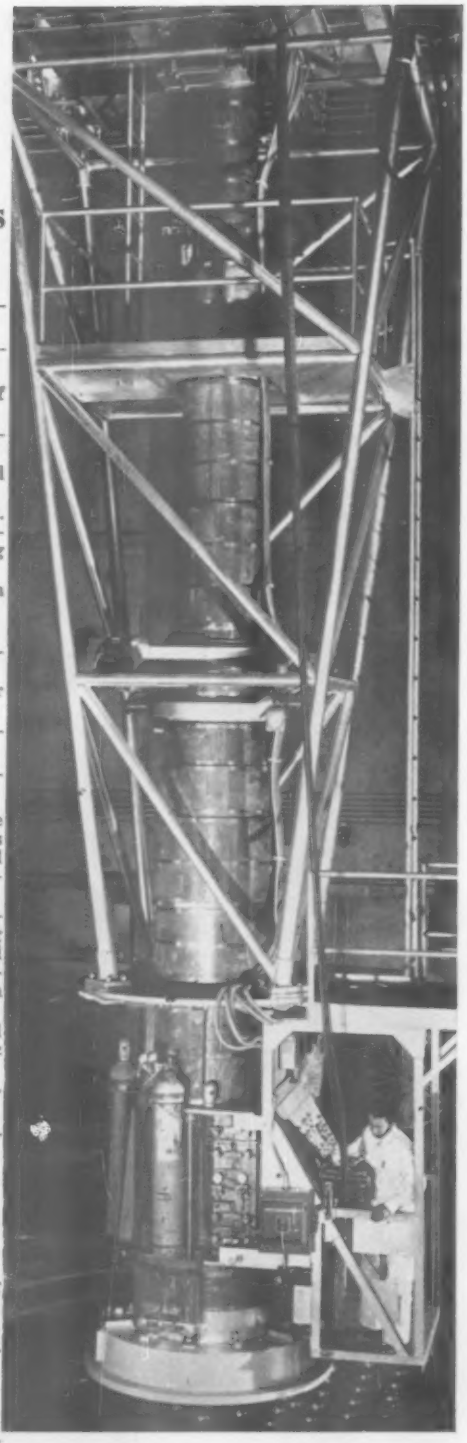

SRE Fuel Handling Cask. The Sodium Reactor Experiment and the Organic Moderated Reactor Experiment are both in successful operation. Plans for several central station plants based on these experimental power reactors are underway. AI is also conducting an advanced power reactor study for Southwest Atomic Energy Associates. Overseas, AI has already sold 5 reactors, and is affiliated with ASEA of Sweden and the new company INTERATOM (with DEMAG, West Germany).

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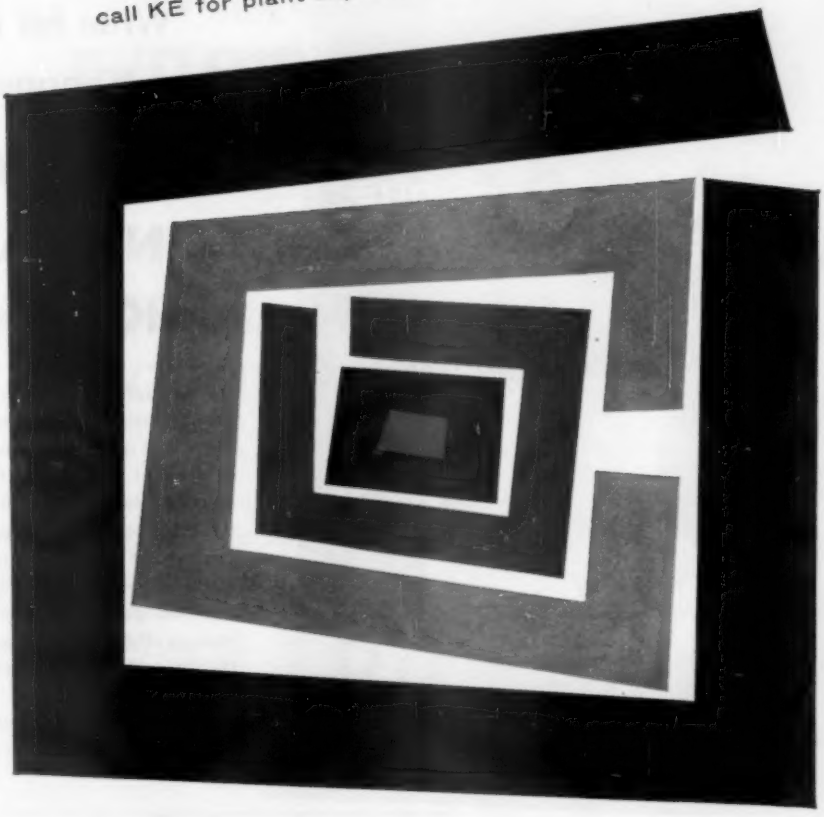

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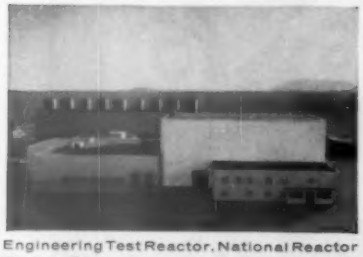

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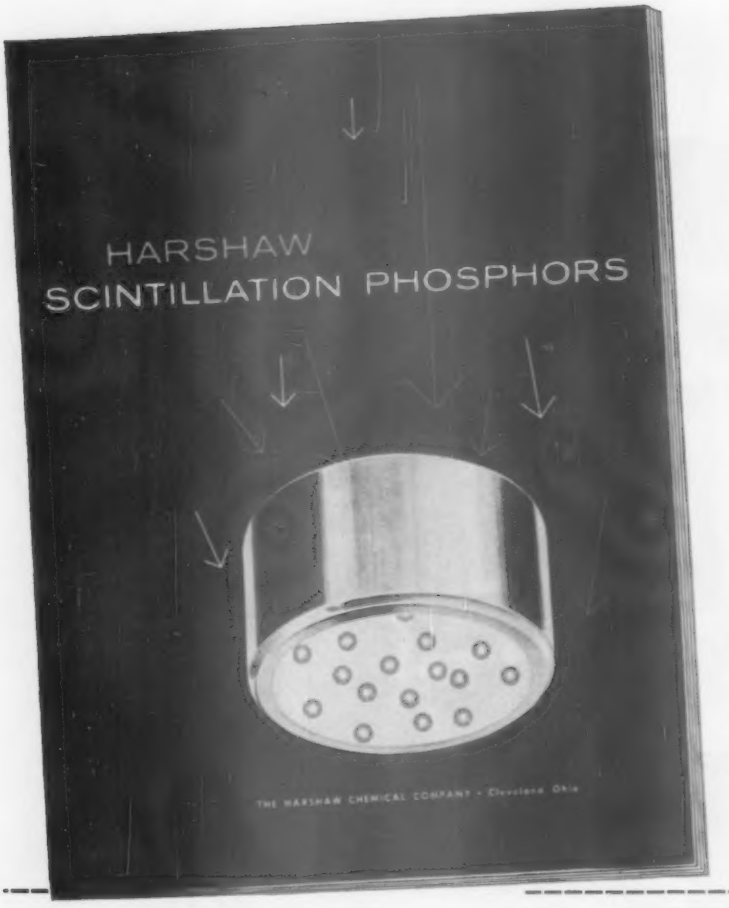

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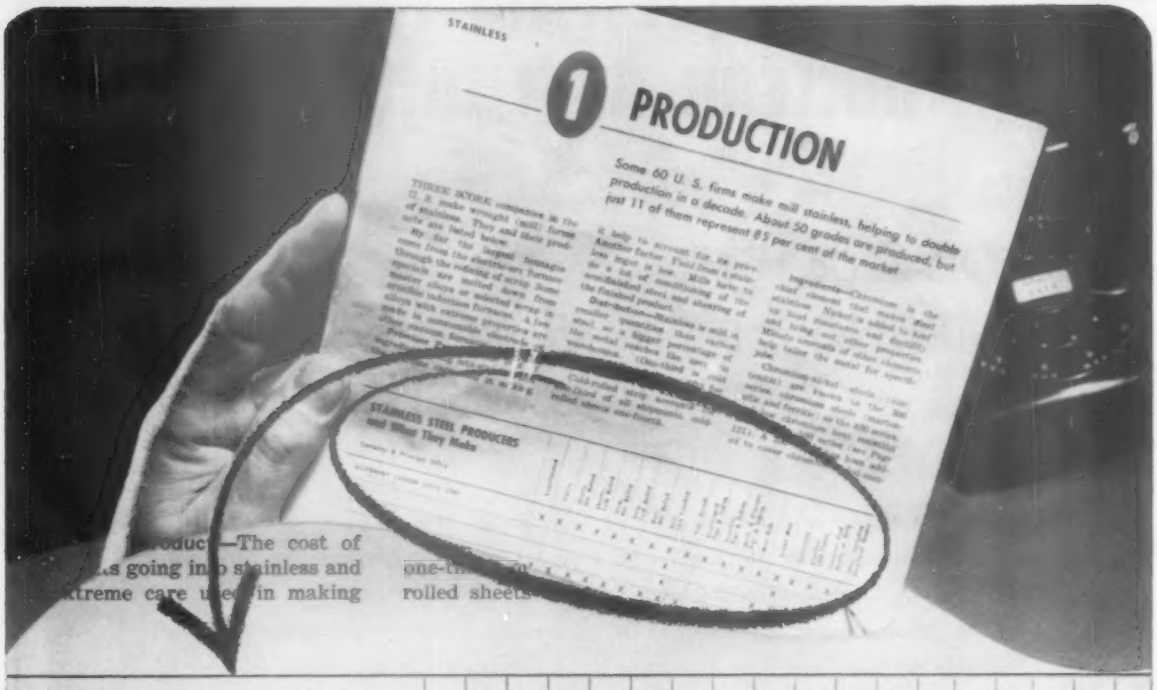
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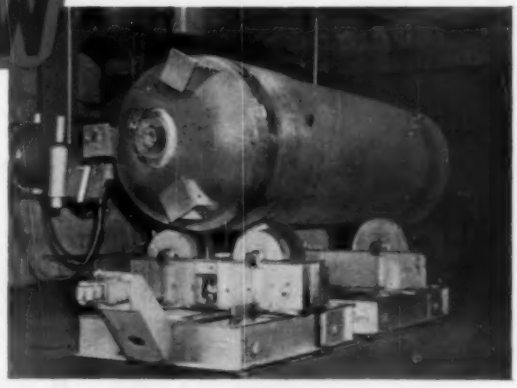
Construction view of one of the steam separating drums at Shippingport during the construction of the plant. In operation, pressurized water from the reactor is circulated through stainless steel tubes in the heat exchangers, where boiler water in the exchanger shell is converted into steam. The steam-water mixture flows upward through risers to the steam separating drum, where the steam is separated, dried and delivered to the turbine generator.

The pressurizer vessel is X-rayed at Foster Wheeler's Mountaintop plant to make sure all welds are flawless. This vessel maintains system pressure and contains system surges. Steam generated by electric heaters establishes and maintains the pressure. During negative surges, additional steam is flashed from the hot water in the bottom section. During positive surges, pressure is reduced by water spray injected into the vessel.



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As a sub-contractor to Westinghouse, Foster Wheeler designed and fabricated two of the four steam generators, each consisting of a heat exchanger, steam drum and interconnecting piping.

In addition, Foster Wheeler supplied the 300 cu ft pressurizer which maintains primary loop pressure for all four of the generators.

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31

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The L&N control panel for Livermore Pool-Type Reactor, California.

L&N controls on Experimental Boiling Water Reactor, Illinois.

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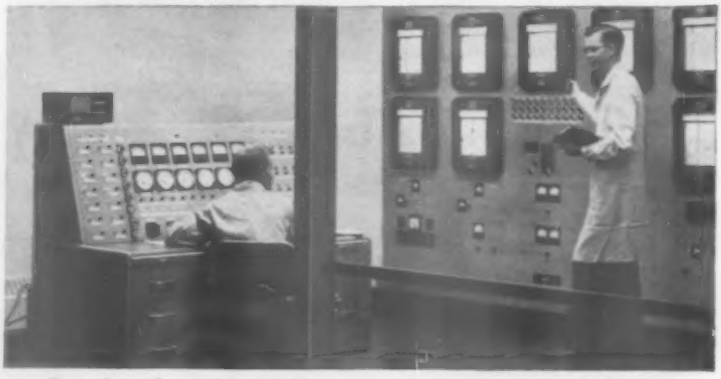
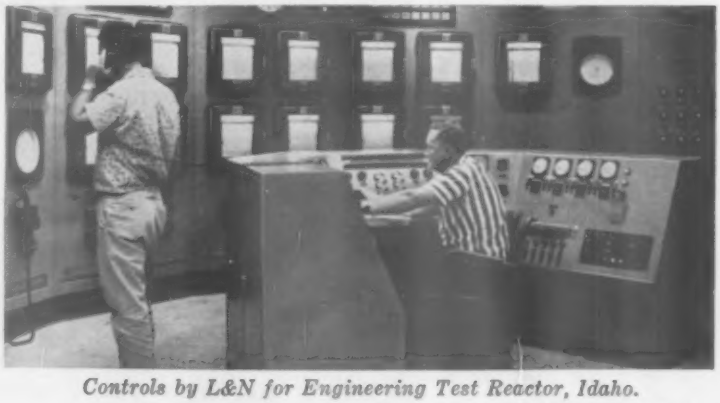


Console and panel by L&N . . . Ford Nuclear Reactor, Michigan.



Controls by L&N for Engineering Test Reactor, Idaho.

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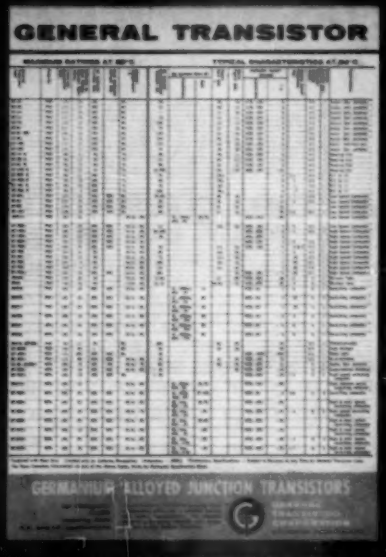

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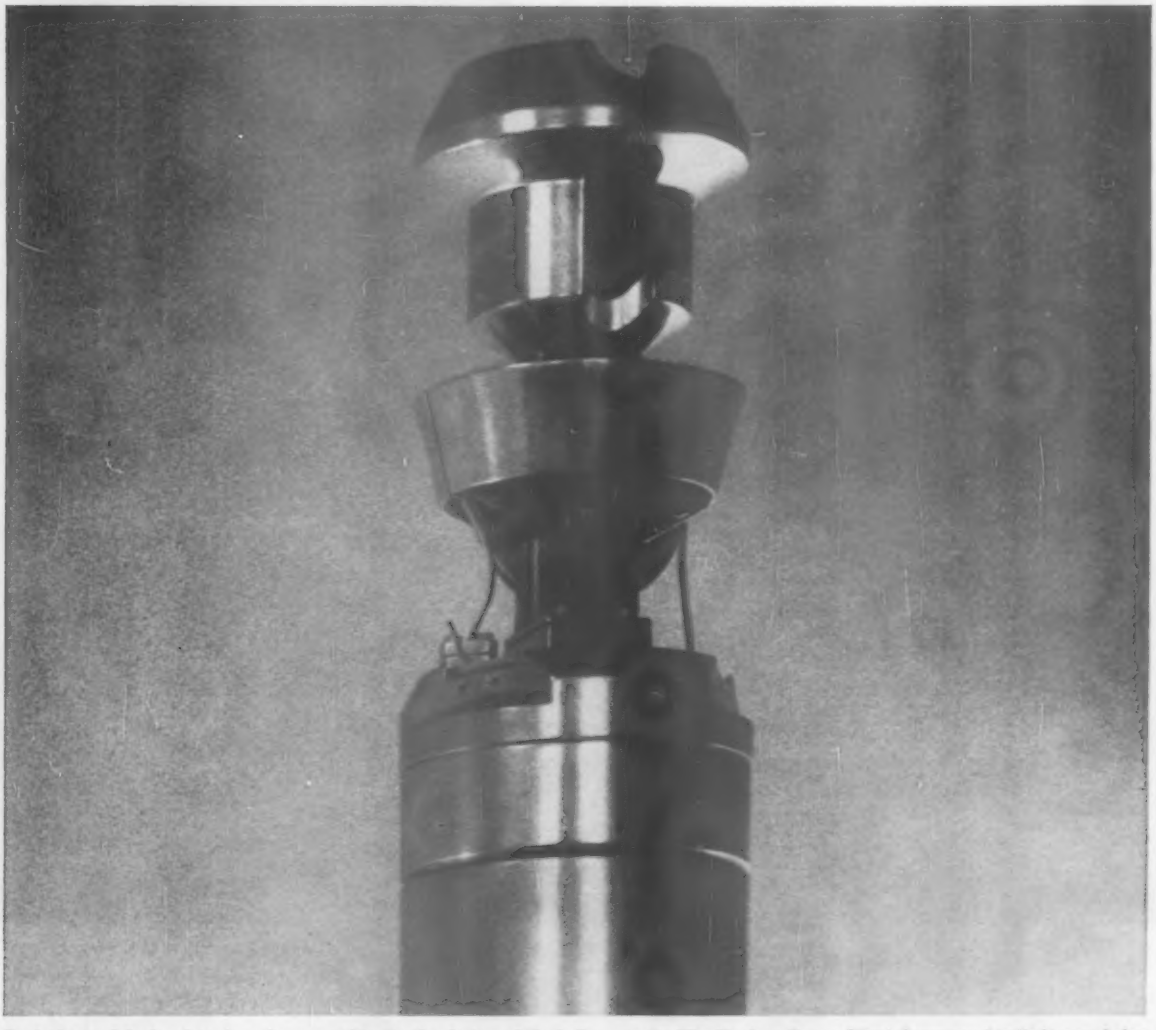

Part of a model of a charging plug assembly (to the design of C. A. Parsons for The Nuclear Power Plant Company Limited) now being produced for Bradwell nuclear power station.

The know-how on gas-cooled reactors

Consider these facts. In 1951, the graphite-moderated gas-cooled reactor was considered barely feasible as a source of power. By 1953, 70,000 kW station, competitive with conventional stations, had been designed. This was Calder Hall.

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This fantastically rapid advance is largely a matter of straightforward engineering know-how gained through the construction and operation of Calder Hall —in which the companies of Tube Investments Limited played their part. This know-how is still growing fast as we work on components for the new stations. It, and our ability to do things with tubes that hardly anyone else can accomplish, are at the service of all atomic engineers.

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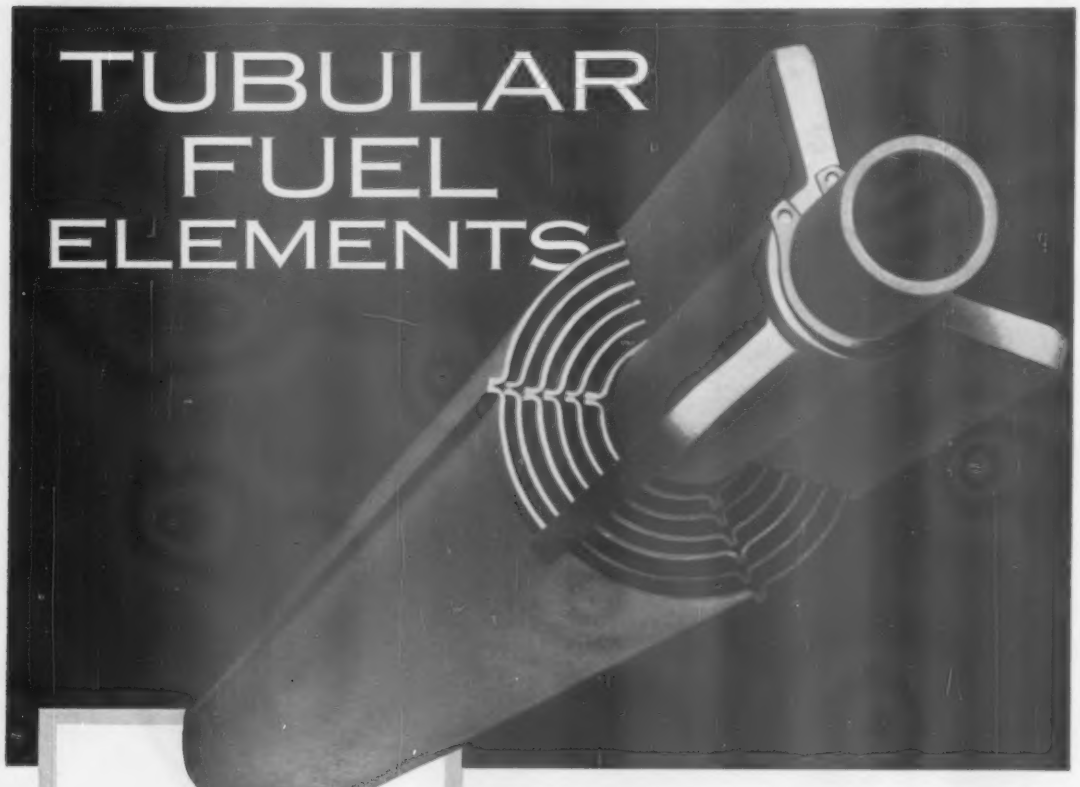
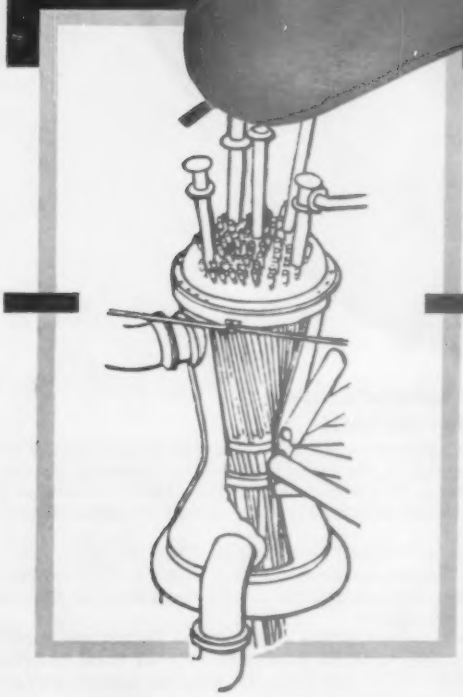


▲ FUEL ELEMENTS for the Materials Engineering Test Reactor, which is scheduled for completion at Mol in 1959 as Belgian Reactor 2, consist of six concentric tubes held by "spiders" at either end on a central irradiation tube. Water gap between tubes is 118 ± 15 mils. Each fuel tube consists of three flat plates formed and brazed together along their 38.671 ± 0.004 in. length; each 50 ± 3-mils-thick plate has a core of U-Al alloy clad with 15 ± 2 mils of aluminum on both faces.



▲ The H_2O-cooled core of NDA's METR will produce irradiation fluxes of 2.4×10^{15} $en/cm^2/sec$ and 6.2×10^{14} $tn/cm^2/sec$ with a rated capacity of 50 Mw of heat. The skewed arrangement permits easy access to each fuel element and experiment during operation.

M & C NUCLEAR, INC. is pleased to be associated with Nuclear Development Corporation of America and Centre d'Etude de l'Energie Nucleaire in developing this new type of fuel element for the BR-2. This project is another example of cooperative effort by the designer, user, and fabricator of fuel elements — design and performance tests by NDA and CEN, fuel manufacturing development by M & C Nuclear. **M & C NUCLEAR, INC.** forms natural, depleted, and enriched uranium, thorium, and their alloys and cermets into a wide variety of shapes — including foil, plate, slab, disc, wire, rod, and tube — and assembles them into fuel elements and modules of many configurations. With its depth of experience in fabricating over 11,000 lbs of U^{235} into fuel elements, its 136,506-ft^2 facility, staff of approximately 850, and qualified vendors, M & C offers its services in developing and manufacturing fuel and core components for projects large or small.

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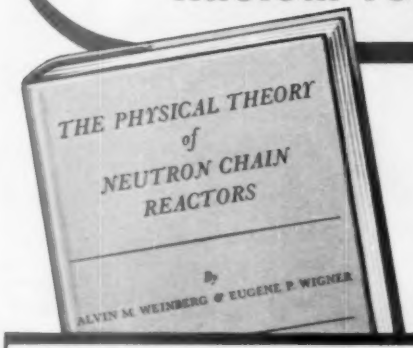

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THE AUTHORS

Eugene P. Wigner, Thomas D. Jones Professor of Mathematical Physics at Princeton, is recognized as one of the world's foremost theoretical physicists.

Alvin M. Weinberg is the Director of the Oak Ridge National Laboratory. Under his leadership this laboratory became prominent in the design and development of reactors.

The two authors began their collaboration in reactor theory during the War when Professor Wigner was head of the Theoretical Division of the Chicago Metallurgical Laboratory. This book is an outgrowth of their many years of work in nuclear physics, in reactor theory and in reactor design.

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14. General Applications of Homogeneous Reactor Theory
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16. Non-Uniform Reactors and the Method of Groups
17. Perturbation Theory
18. Reactor Kinetics
19. Heterogeneous Reactors—The Thermal Utilization
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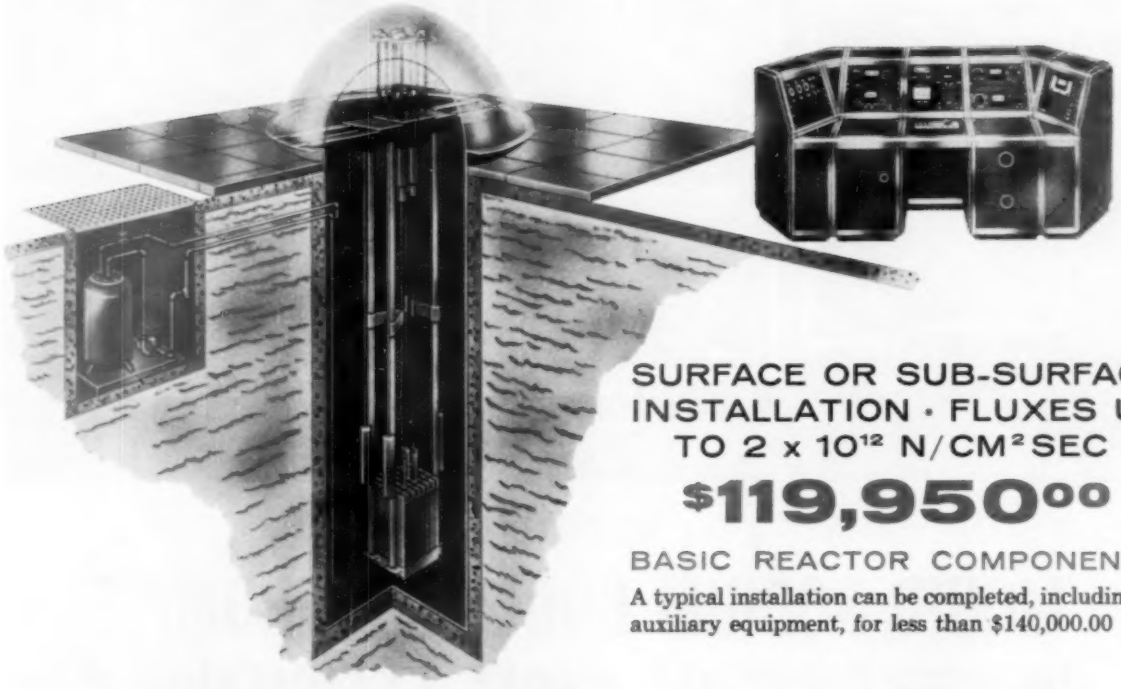

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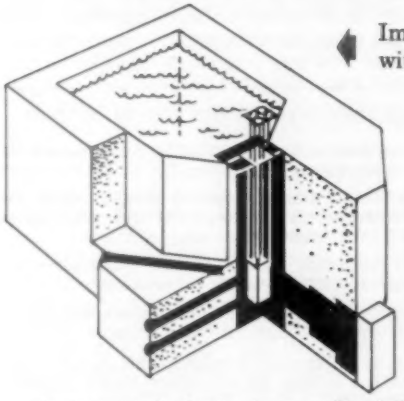

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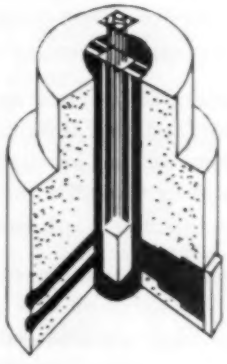

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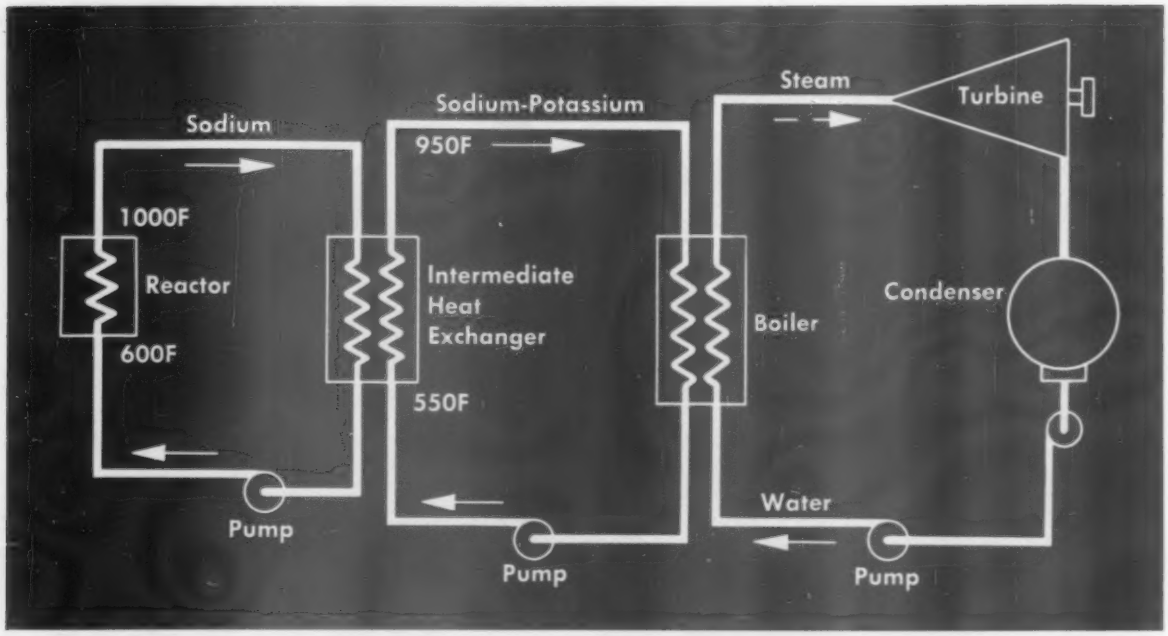

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Liquid sodium has this important advantage over other coolants in nuclear power reactors—it delivers heat at very high temperatures without high pressures. In consequence, it offers a promising route to steam cycle efficiencies comparable to those of modern, conventional power plants.

Today, EBR-I at Arco, Idaho—a fast breeder reactor, and SRE at Santa Susana, Cal.—a sodium-graphite reactor, are testing sodium coolants, and attempting to realize the power efficiencies inherent in this method of heat transfer.

Four other reactors, planned or under construction, will carry on this work. See the list below. Results indicate that sodium is an ideal material for heat transfer in nuclear power installations of the future.

Other advantages of sodium coolants include: relatively low neutron-absorbing characteristics, excellent heat transfer properties, low melting point and high boiling point (liquid between 207°F and 1621°F). These coolants do not polymerize, carbonize or decompose.

For complete information on sodium, send for U.S.I.'s free 40-page brochure "Handling Metallic Sodium on a Plant Scale." And if you want answers to your specific questions, our technical service men will be glad to work with you.

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- Sodium Reactor Experiment (SRE), Santa Susana Mts., Cal.—Sodium-graphite reactor—7,500 KW (operational)
- Experimental Breeder Reactor-I (EBR-I), NRTS, Arco, Idaho—fast breeder reactor, sodium-potassium cooled—15,000 KW (operational)
- PRDC Fast Power Reactor, Monroe, Mich.—fast breeder reactor—100,000 KW (under construction)
- Consumers Public Power District, Hallam, Neb.—sodium-graphite reactor—75,000 KW (design stage)
- Experimental Breeder Reactor-2 (EBR-2), NRTS, Arco, Idaho—fast breeder reactor, sodium cooled—20,000 KW (design stage)
- Chugach Electric Association Reactor, Anchorage, Alaska—heavy water moderated, sodium cooled—10,000 KW (development stage)

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SPACE FLIGHT and NUCLEAR PROPULSION

A drastic reduction in vehicle mass ratios... substantially increased specific impulse values... a capability for achieving very high speeds... these are some of the significant advantages that will come from the application of nuclear energy to space flight.

A number of different propulsion systems have been proposed to utilize nuclear reactions. The simplest system consists of a fission reactor through which the propellant is passed, heated, and then expanded through a rocket nozzle. Fission reactors can also be employed as a source of energy to generate electric power, which in turn can be used to accelerate ions or charged particles, or to create and accelerate a plasma. And fusion reactors, when developed, can be used to generate electric power for the same purposes. In addition, in the case of the fusion reactor, there is the attractive possibility that the reaction energy can be used directly without conversion to electric power.

The fission-powered thermal propulsion system will probably constitute one of the next major advances in space technology. As an example of the gain which can be achieved, consider a vehicle with a payload weight of about 25 tons for a manned flight to one of the nearer planets, landing, and returning. Powered by chemical rocket engines, the takeoff weight for such a vehicle would be 50,000 tons. But powered by a fission-thermal propulsion system, weight at launch would not exceed 500 tons... a 100-fold reduction in the mass ratio. Considerably greater gains are predicted for the more advanced systems.

Systems studies and advanced research in the application of nuclear energy to the requirements of space flight are in progress at Space Technology Laboratories. This work illustrates the emphasis at STL on the exploration and development of new concepts and techniques in ballistic missile and space technology.

Both in support of its over-all systems engineering responsibility for the Air Force Ballistic Missile Program, and in anticipation of future system requirements, STL is engaged in a wide variety of analytical and experimental research. Projects are in progress in electronics, aerodynamics, hypersonics, propulsion and structures.

The scope of activity at Space Technology Laboratories requires a staff of unusual technical breadth and competence. Inquiries regarding professional opportunities on the STL Technical Staff are invited.

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ALCO Products, Inc. technicians check operation of Army Package Power Reactor on a Honeywell control panel at ALCO's criticality facility in Schenectady, N.Y.

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TUBE-TURN Welding Fittings serve Shippingport Atomic Power Station

Shippingport is a joint project of the U. S. Atomic Energy Commission and Duquesne Light Company. Westinghouse developed and designed the nuclear portion of the plant under the direction of and in technical cooperation with the Naval Reactors Branch, Atomic Energy Commission. Duquesne Light Company built the turbine-generator portion of the plant, contributed $5,000,000 toward the construction of the reactor plant and is operating the entire station.

Installing a line in a section of the reactor plant at Shippingport. Fitting is a TUBE-TURN Type 304 stainless steel elbow. Nuclear portion of plant: designed and developed by Westinghouse Electric Corporation under contract with the Atomic Energy Commission; architects, Stone & Webster Engineering Corporation; contractors, Drava Corporation.

Welded piping systems play an important role in assuring the dependable, efficient performance of the Shippingport Atomic Power Station . . . the United States' first full-scale nuclear power plant to generate electricity for civilian use. Sizes range from 18" Type 304 stainless steel for reactor coolant water lines at 2000 psi, down to ½" carbon steel steam service lines.

Tube Turns, pioneer in piping for nucleonic applications, supplied many of the welding fittings for the approximately 40 piping systems in the station. The TUBE-TURN* line of seamless, forged fittings for reactor piping includes stainless steels, stainless-clad carbon steel, chrome-moly steels, aluminum and titanium. For consultation on nuclear power piping problems, call our nearest office.

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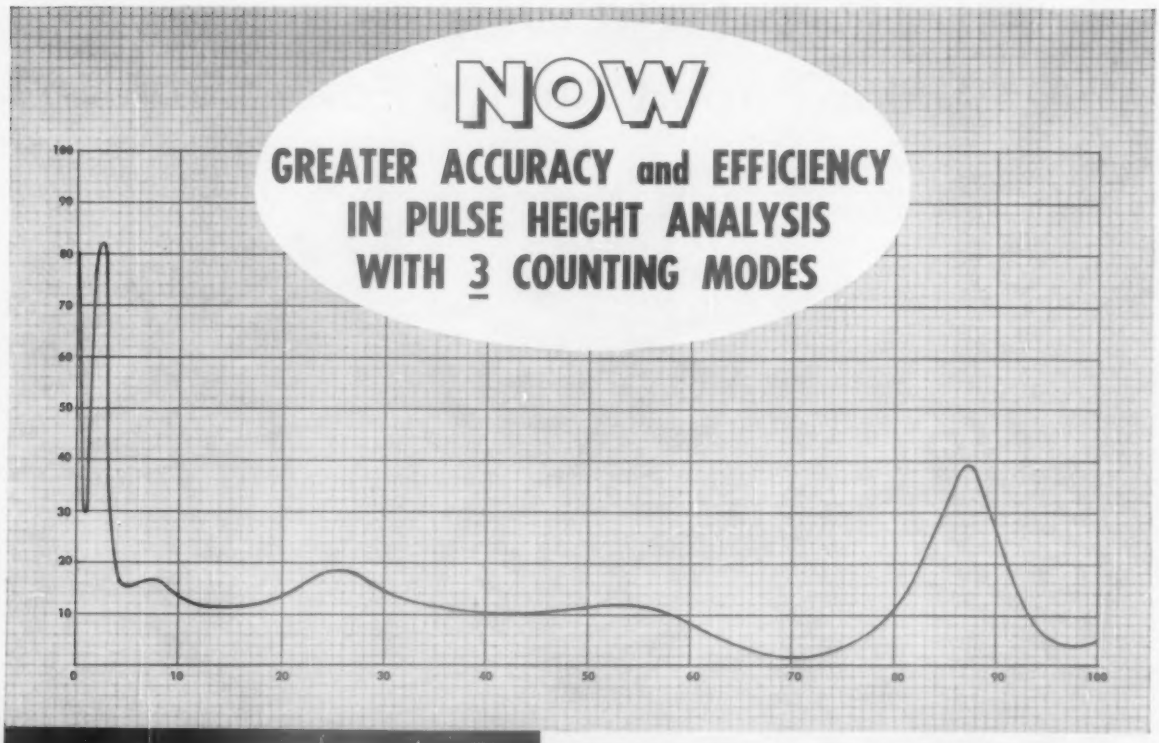

A C_s 137 spectrum taken in a standard 0-10 volt window mode. The *upper limit* mode of the PA-3B would count pulses between the limits of the photo peak.

TMC PA-3B AMPLISORTER
counting modes:

1. **INTEGRAL MODE** — for counting all pulses above base line
2. **WINDOW MODE** — for standard window counting as in conventional analyzers — window variable 0-10 volts
3. **UPPER LIMIT MODE** — for wider differential range counting — upper and lower limits each variable 0-100 volts

The TMC Model PA-3B combination single-channel pulse height analyzer and linear amplifier attains a new degree of efficiency and accuracy through an added *third* counting mode. Where other analyzers can go no further than counting in a window mode, the PA-3B provides an *upper limit* mode to count between any desired lower and upper limits on the spectrum. This gives the PA-3B an extremely wide differential range and makes it the most capable instrument for such precise operations as isotope monitoring, x-ray diffraction measurement and other experimental set-ups where extreme instrument efficiency is essential.

The linear amplifier section is a non-blocking Chase Higinbotham long-tail-pair type. It features binary gain control from 1 to 64, maximum gain of 8000, and fixed RC clipping. (Negative input and 1.5 us. clipping are standard, but positive input and other clipping times may be specified.) Price of Model PA-3B, $700.

Where *two-channel analysis* is desired, the Model PA-4A Dual-Channel Analyzer provides all the features of the PA-3B, but has a second analyzer unit in place of the linear amplifier. Price of the PA-4A is $900.

Complete data and specifications on the PA-3B, PA-4A, or any of a variety of TMC radiation measurement instruments are available on request.

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Second Construction Report on Westinghouse Testing Reactor

The supporting framework for the pressure vessel rises above the canal at WTR.

This 20-mw reactor will be available to industry in the spring of 1959 for high-flux irradiation experiments, including those conducted under high-temperature, high-pressure conditions. Auxiliary services will include: hot cells, rabbit tubes, reactivity measuring, critical experiment and gamma irradiation facilities.

For contract reservations and assistance in planning nuclear materials tests, write: Westinghouse Testing Reactor, P.O. Box 1075, Pittsburgh 30, Pennsylvania.

Photo taken May 2, 1958.

J-59002

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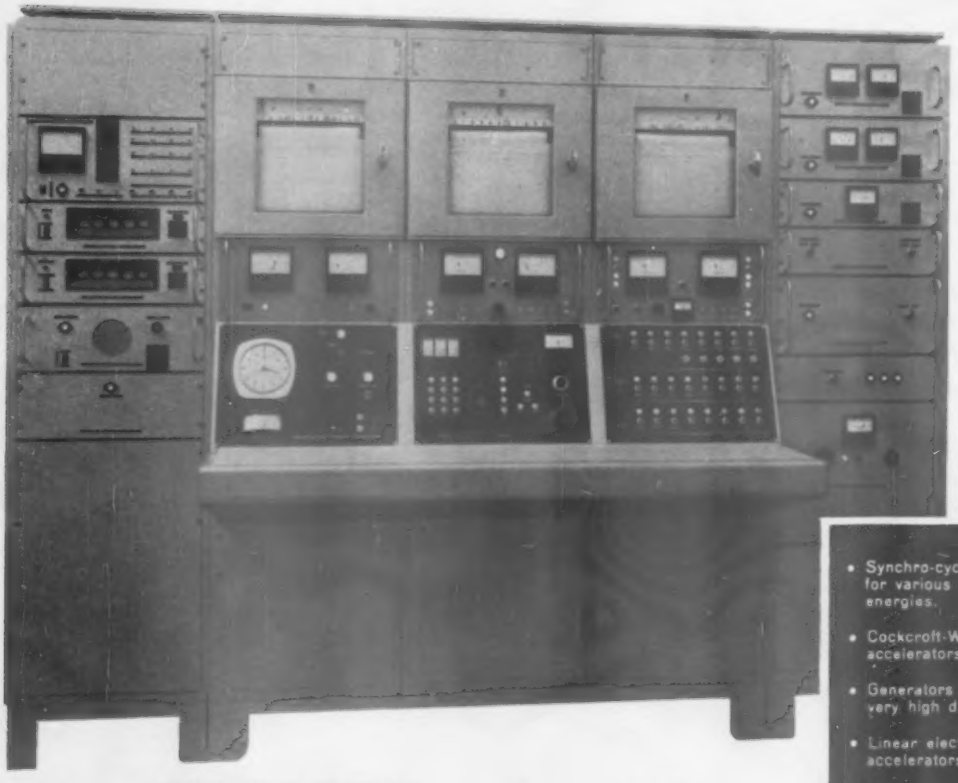

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Shown here is a complete instrument panel for a "swimming pool" nuclear reactor. The panel contains full flux measuring facilities covering the entire range of operation. All controls and indicators for the operation of control rods, safety system, multi-point area monitoring and auxiliary units are included. The reactor will be installed at Delft Technical University. Similar systems designed to exactly fill your needs can be supplied.

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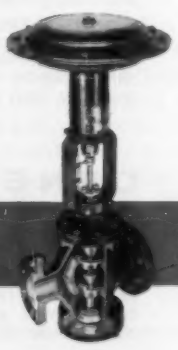

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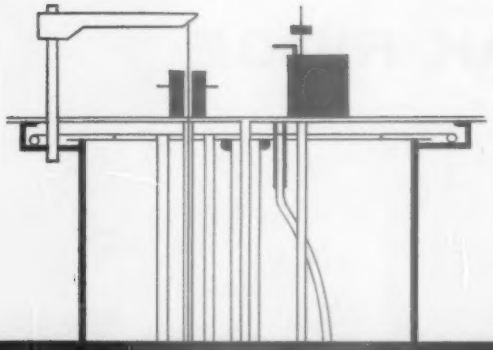
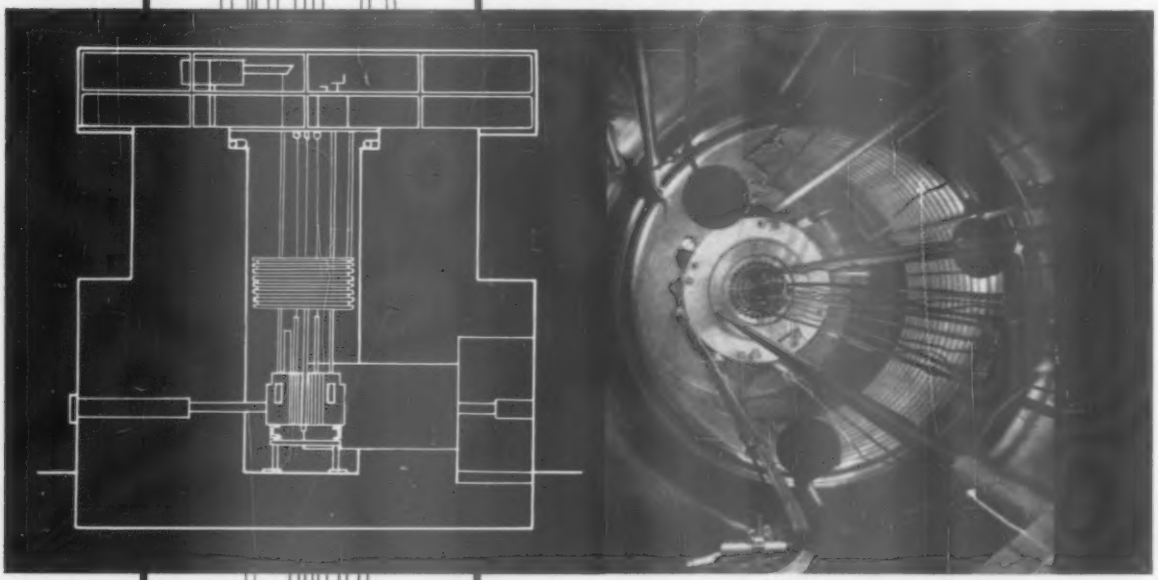
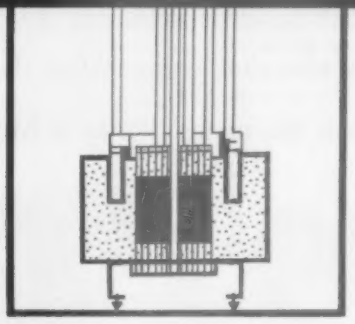


A highly successful series of initial TRIGA experiments and tests have been completed recently by General Atomic Division of General Dynamics Corporation. Scientists and engineers of the Division's *John Jay Hopkins Laboratory for Pure and Applied Science* reported results in complete accord with theoretical predictions of the properties and capabilities of this new reactor concept.

These tests included power runs at more than 10 times the reactor's design continuous power rating of 10 kilowatts. They conclusively verified the inherent safety of this new training, research and isotope-production reactor, which was conceived and developed by General Atomic.





Designed specifically for use by academic institutions, medical centers and research laboratories, TRIGA is available either in the Mark I below-ground, minimum cost version or the new, Mark II above-ground installation. TRIGA Mark II design provides a thermal column and horizontal beam ports in addition to facilities for training, research and isotope production. Both versions are equipped with a rotary irradiation rack, central thimble and pneumatic system for very short-lived isotope production.

Combining simplicity, versatility and inherent safety with practical operating power, TRIGA Mark I and Mark II represent a major forward step in reactor design. Specifications and additional information are available upon request.

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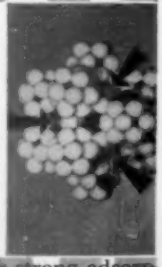
Chemical-Loaded Molecular Sieves—Latent Curing Aids in Rubber and Plastics

Rubber and plastics fabricators need faster curing systems. The use of more active agents for rapid curing reactions has been restricted, because their use generally results in formulations difficult to process and store. This problem is serious at the high temperatures reached during the processing of rubber formulations. A novel series of latent curing aids, called LINDE Chemical-Loaded Molecular Sieves, now make it possible to use these active compounds to obtain faster, more effective curing systems, while still maintaining processing safety.



In LINDE Chemical-Loaded Molecular Sieves curing aids are "locked" within the pore structure of the Molecular Sieves by strong adsorptive forces. The active compounds, when loaded on Molecular Sieves, are effectively isolated from the rubber or resin formulation during processing and storage. However, at curing temperatures, which are generally higher than processing temperatures, the active compound is released from the Molecular Sieve to accelerate the curing reaction.

In this way, Loaded Molecular Sieves permit the use of highly active compounds to obtain fast cures, without sacrificing processing safety or pot life. Now, even vulcanization agents previously considered too active or volatile for practical use, may be used with processing safety.

Chemical-Loaded Molecular Sieves can be used as latent accelerators and curing agents in a variety of rubber and plastics formulations including styrene-butadiene rubber, natural rubber, Neoprene, nitrile rubber, epoxy resins, rigid vinyl plastisols and others. Loaded Molecular Sieve CW-2015 (di-tertiary butyl peroxide) is being used commercially in the curing of silicone elastomers and rigid vinyl plastisols. Loaded Molecular Sieves are now being investigated by many processors of rubber and plastics in such items as tires, mechanical goods, hose, belting and footwear. For further data, write to Molecular Sieves Department NU-7, LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y.

Radioactive Krypton

Krypton 85 is a radioactive isotope of the inert atmospheric gas, with a half-life of 9.4 years.

Radioisotopes such as Kr-85 are relatively inexpensive and new uses for them are being found every day.

One application is in tracer element testing of hermetically sealed encapsulated transistor devices. Another is in an "external" non-electric illuminating lamp which uses Kr-85 to activate a phosphor coating on the inside of a glass globe. Studies at the National Institutes of Health have shown that Kr-85 can be used to detect abnormal heart openings. 99 per cent of Kr-85 radiation is non-penetrating, quite safe, even for repeated exposures.

LINDE is marketing Kr-85 as an additive to non-radioactive rare gases (argon, helium, neon, krypton and xenon) individually or as mixtures. LINDE does not sell Kr-85 in pure or concentrated form. The other rare or inert gases, with Kr-85 added, will normally be available only in Atomic Energy Commission-approved, specially-marked cylinders.

Purchasers must be licensed by local or regional A.E.C. offices except for purchases of one microcurie or less. Non-licensed purchasers of one microcurie each may have 10 such cylinders on hand at a time.

LINDE's price for Kr-85 additions will be based on the radioactive level of the gas mixture expressed in millicuries of activity (N.T.P.) per liter. For additional information, write to Rare Gas Department NU-7, LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y.

Three-Level Ruby Maser

The Maser is a microwave amplifier utilizing energy stored in a molecular or atomic system. Emission of this energy is stimulated by the input signal. Masers operate at liquid helium temperatures and have incredibly low noise levels approaching zero db. Recently a University research laboratory* used

LINDE single crystal synthetic ruby (Al_2O_3 with Cr_2O_3 additive) in a three-level solid state Maser. The ruby crystal was placed at the center of the Maser's tuned cavity and a magnetic field of 4200 gauss was applied. To bring electrons from a ground state into a permissible higher energy level, a pumping frequency of 24 kMc was used and the Maser successfully amplified signals at 9.3 kMc.

LINDE also supplies other crystals including rutile, spinel and sapphire (Al_2O_3). Sapphire is used in infrared optical systems, windows for high power microwave tubes, spacers and supports in vacuum tubes, radiation pipes. It has strength at elevated temperatures, melts at 2040°C, is hard, inert, nonporous and can be sealed to metals and glasses. Sapphire is currently available in the shape of domes, windows up to 4½ inches in diameter, rods and special configurations.

For further data write to Crystal Products Department NU-7, LINDE COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, New York.

*"Maser Action in Ruby," by G. Makhov, C. Kikuchi, J. Lambe, and R. W. Terhune. "Physical Review," Volume 109, Number 4, Page 1399, Feb. 15, 1958.

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This Cobalt 60 irradiator is safe and easy to operate — junior personnel can handle irradiations with a minimum of supervision. Automatic timing ensures removal of the sample on schedule.

Access tubes to the 220 cubic inch sample chamber make more elaborate experiments practical, by permitting irradiation of gases or liquids under flow conditions. Also, the tubes provide for the introduction of cooling coils or electrical circuitry.

For complete technical data on the Gammacell 220 and kilocurie Cobalt 60, please write to

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With the completion of the world's first privately owned heavy water research reactor, at the Massachusetts Institute of Technology, comes a new and powerful instrument to further man's knowledge in the peacetime use of atomic energy. As prime contractor responsible for the complete engineering design and construction of this facility, ACF Industries, Incorporated is proud to join with MIT in this achievement.

The MITR will operate at 1000KW and produce fluxes in excess of 10^{13}n/cm²/sec. This inherently safe facility, located near the campus, includes a unique medical therapy room providing entirely new approaches to nuclear medical research techniques — a full range of experimental ports and thimbles — gamma irradiation room — chemistry hot labs — reactor control room — and equipment for servicing the reactor building.

Other ACF nuclear projects include research and test reactors under construction in Italy, Holland, Sweden and the U.S. . . . and gas cooled and boiling water power reactors being designed for the U.S. Atomic Energy Commission.

acf **NUCLEAR PRODUCTS–ERCO**

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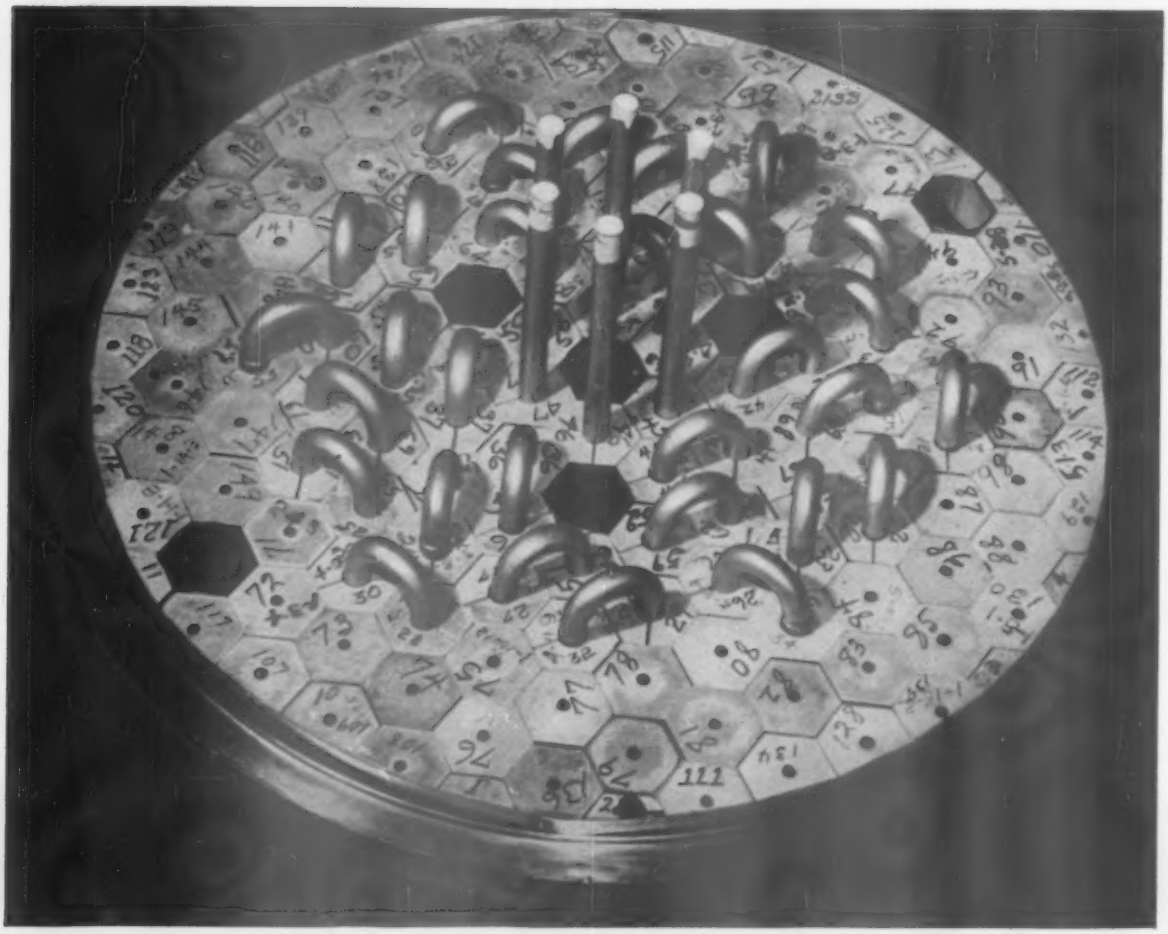

Inconel test reactor operates with molten fluorides at 1500°F

The Aircraft reactor experiment, reported in ORNL 57-6-69, showed that molten fluoride salt reactors develop promising thermal efficiency.

Other advantages include modest pressures, thorium solubility, no water decomposition problem, small absorption cross sections, good heat transfer properties.

In this system, Inconel* nickel chromium alloy was used throughout (reactor, lines, tanks, and exchangers) to circulate molten fluorides containing dissolved uranium fluoride fuel at temperatures to 1500°F, or more. It was also used for the 2-in pressure shell and for strip heaters clamped around shell (left photo).

Joints and closures were Heliarc welded and inspected by dye penetrant and gamma graphing

The ORNL report states: ". . . our considerable experience with these systems strongly suggests that the corrosion problem is a tractable one."

Do you have a corrosion problem involving fluorine or fluorine compounds? Write to our Development and Research Division for assistance.

New booklet on fluorine handling

Inco's new 24-page booklet "Handling Fluorine and Fluorine Compounds" gives corrosion data on fluorine and hydrofluoric acid, and summarizes case history data on solution of corrosion problems in many installations. Write for your free copy.

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INCO NICKEL ALLOYS

NUCLEONICS
ATOMIC POWER
NUCLEAR ENGINEERING
APPLIED RADIATION

JULY, 1958

Good Luck, Mr. McCone!

IT is hard to find a parallel in American history where a civilian body such as the Atomic Energy Commission has had such vast powers and responsibilities in three diverse areas: (1) the military strength of the country; (2) international relationships; and (3) the vitality and future of a brand new industry.

It is, of course, because the Commission is charged with these duties that the fate of the atomic energy community is intimately linked with the successes and failures of AEC. This will undoubtedly continue to be the case for at least the next decade.

And so, for the past 11 years, the performance of the five-man Commission, particularly that of its chairman, has been watched closely.

As this is being written, Lewis L. Strauss is preparing to step down from the chairmanship he has held since 1953, and John A. McCone, named as his successor as a Commissioner, is expected to step into the key spot. In addition, the resignations of five other important members of the AEC staff has been announced (see p. 21).

Surely, it is a truism to point out that the Commission and its program are at a very trying point in U. S. atomic energy history. Bitterness and acrimony have surrounded discussions of the program in the past several years. Confusion exists in the minds of observers, both in this country and abroad, on objectives and directions of the U. S. effort in nuclear power. This is notwithstanding the fact that the basic reactor development program that got its start eight or nine years ago and was expanded into a formal program four years ago has been producing extremely useful results and has given the U. S. a very well rounded effort.

Now the time has come to stake out the future. Before this can be done, however, there needs to be some mending of fences—a development of harmony both within the executive branch and between the executive and the Congress. Although the fights with the Congress have received the most publicity, there has been a growing inability to agree within the AEC staff, between AEC and the State Department (e.g., on the horribly bungled Euratom discussions), and between AEC and the Bureau of the Budget.

A major cause of the disunity up and down the line has been the disagreement on whether the U. S. should have a clear-cut long-term nuclear power development program or whether a year-to-year one is sufficient. AEC has been *against* a long-term plan. The Joint Committee on Atomic Energy has been *for* one. Under extreme pressure from JCAE, AEC last month came in with such a proposal, including a recommendation that the U. S. strive to achieve economically competitive nuclear power abroad in five years and within the U. S. in ten years. However, because it was apparent that AEC didn't really have its heart in its proposal, the JCAE plans to work up its own recommendations.

Thus, the issue is drawn. Even if personality conflicts are removed, there will undoubtedly be a major struggle between AEC and the Congress over what the program for the future should be.*

THIS, then, is the challenge to Mr. McCone and his colleagues. There is a vital need for AEC to take on the mantle of leadership in atomic energy. It should not abdicate it to the Joint Committee. We believe it is to the best interests of the U. S. to have a dynamic, clear-cut program for achieving economic nuclear power in the U. S. within the next ten years. We believe it is the responsibility of AEC to propose a challenging program—and for the Joint Committee to continue its useful watchdog function by constructively examining AEC's program. We believe that private industry should have an important role in the continuing program. But we also believe that where the national interest is at stake and where industry is unable to assume the burden, AEC should not hesitate to build reactors that are basic to a ten-year program.

This, we believe, is the challenge, Mr. McCone. NUCLEONICS wishes you the best of luck!

Jerome D. Luntz

* After this editorial was written, Sen. Anderson, in a very statesmanlike speech, presented an excellent basis for the development of nuclear power in the U. S., a basis that should appeal to most points of view (see p. 17).

Prime Movers for the Space Age . . .

NUCLEAR ROCKETS

NUCLEONICS reports on the basic principles (below), the engineering problems (p. 66), current progress (p. 69) and future application (p. 73) of nuclear energy for rocket propulsion

Basic Principles

By JERRY GREY
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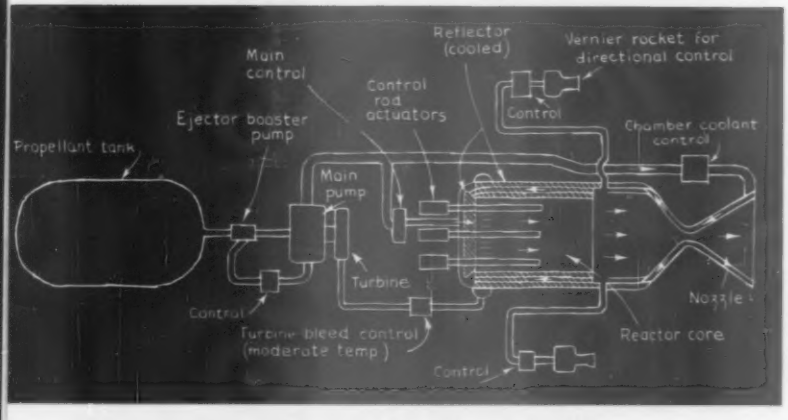


Here's How Nuclear Rockets Work

Nuclear rocket uses a solid-fuel-element reactor to heat a single liquid propellant. Some of the propellant is first used to cool chamber walls and reflector before injection into the reactor chambers. Nuclear rockets differ from liquid-propellant chemical rockets as follows (see box, p. 64):

First, since exhaust temperature depends on both propellant flow rate and reactor power level, thrust can be changed independently of flow rate. Since there are now *three* interdependent parameters (pressure, temperature and flow rate) in contrast to the two parameters (flow and pressure) of the chemical rocket, the control system is more complicated.

Second, the large reactor size and mass rules out directional thrust control through gimballing of the chamber. Thus jetevators, small auxiliary exhaust nozzles, or other directional devices have to be used.

Third, radiation dose rates are high enough to cause radiation damage to unshielded auxiliaries, controls and guidance equipment.

Finally and most important, in the chemical rocket the propellant chamber temperatures are self-generated and are always much higher than the walls or any other metallic structure, all of which can be conveniently cooled to well below, say 2,000° F. (Many modern chambers operating at temperatures in excess of 6,000° F are made of aluminum alloys that melt at around 1,400° F.) In the nuclear rocket, since the heat is transferred from the solid fuel elements to the propellant gas, the hottest part of the reactor core must always be at a temperature slightly above the final propellant temperature. Thus structural materials will always operate far hotter in a nuclear rocket than in a chemical rocket. This is the major limitation of the "conventional" or solid-fuel nuclear rocket.

AN INHERENT ADVANTAGE of nuclear rocket propulsion is the unlimited energy supply of a reactor that can be used to heat a low molecular-weight propellant like hydrogen to much higher exhaust velocities than are possible in chemical rockets operating at the same temperature. The higher exhaust velocities lead directly (facing box) to superior rocket performance. However, the nuclear rocket, since it uses liquid fuel and requires careful synchronization of fuel flow and reactor power will, like a liquid-propellant chemical rocket, be complicated to operate. For this reason the lower-performance solid-propellant chemical rockets will probably be favored for all military terrestrial missions except those requiring extremely large payloads. For extraterrestrial missions, on the other hand, the nuclear rocket becomes indispensable. The "conventional" reactor system pictured at the left, for instance, appears ideally suited for use as a reusable satellite or moon ferry vehicle capable of carrying very large payloads at a nominal cost. For interplanetary travel this first "brute force" design would have to be replaced by more sophisticated approaches to nuclear energy propulsion (see p. 73).

Nuclear vs. Chemical Rockets

Since the conventional nuclear rocket is limited by structural requirements to chamber temperatures even lower than those of the better liquid propellants (see box at left), decreasing the molecular weight of the propellant is the only way the nuclear rocket can gain a significant performance advan-

tage. It turns out, however, that worthwhile gains can be made in this way. Figure 1 compares the exhaust velocities of various chemical combinations with those attainable using the two most popular nuclear propellants, hydrogen and ammonia (*1*). The best of all possible chemical propellants (excluding free-radical systems, which will very likely be more difficult to handle than nuclear systems) is ozone-hydrogen, which provides a v_e of about 13,000 fps at 500-psi chamber pressure. The combustion temperature is about 5,000° F, and the exhaust-gas molecular weight is about 9. A nuclear rocket operating at only 3,000° F, almost 40% *lower*, but using hydrogen with a molecular weight of 2, provides a v_e at the same chamber pressure of over 19,000 fps, or *50%* higher than the best chemical propellant. Now, if the nuclear working temperature is raised to what seems to be an attainable level of 4,500° F, the exhaust velocity increases to nearly 24,000 fps. Furthermore, we have been talking in terms of an ideal chemical-propellant combination that is by no means yet an engineering reality. Compared with the present operational specific impulse levels of about 260 sec (v_e = 8,300 fps) the nuclear rocket is unquestionably superior (see Fig. 1). As chamber temperatures increase, the nuclear rocket advantage becomes even greater due to dissociation of the propellant, which reduces its molecular weight.*

To appreciate what the extra exhaust velocity of nuclear rockets would mean consider the table at right, which lists the burnout velocities needed for various rocket missions. Even using the extremely optimistic relationship of Eq. 1 to convert exhaust velocities to burnout velocities, the chemical propellants shown in Fig. 1 are hard pressed to reach the goals set forth in the table. The escape mission is an impossibility for all the chemicals (in a single-stage rocket), while only some of the fuels can (theoretically) squeeze by the next most difficult missions. On the same basis nuclearly heated hydrogen at only 3,000° F can easily accommodate all the missions proposed.

Nuclear disadvantages. But what

* Since the energy supply of a nuclear rocket is for practical purposes unlimited, it can afford to supply the extra energy of dissociation. Since the chemical rocket derives its energy from joining chemical bonds, it can afford very little energy to break these same or other chemical bonds.

Fundamentals of Rocket Propulsion

In simplest terms, the function of a rocket is to accelerate a payload to a prescribed velocity. (The table shows velocities required for typical missions.) If at the time the fuel burns out, the payload is traveling with proper speed in the proper direction, the rocket has done its job. Thus a good measure of rocket performance is the burnout velocity v_o and the payload weight obtained for a given total take-off weight M_0. These quantities are related by straightforward application of Newton's 2nd Law ($F = ma$). If the resulting differential equation is integrated over time for a single-stage rocket traveling straight up from the surface of the earth one gets

$$v_o = v_e \ln (M_0/M_e) - gt_b + v_0 \qquad (1)$$

Here M_e = burnout mass (M_0 minus the propellant weight), g = the acceleration of gravity, t_b = time to burnout, v_e = propellant exhaust velocity and v_0 = the initial velocity (if any) at takeoff.

Burnout Velocities by Mission

Mission	*Burnout velocity (fps)*
Escape	35,000
Satellite	27,000
ICBM (5,000 mi)	22,000
IRBM (1,500 mi)	15,000
V-2 (200 mi)	5,500

Several conclusions about rocket performance can immediately be drawn from Eq. 1. To make v_o larger the thrust duration t_b should be as short as possible. However, losses from atmospheric drag (not included in Eq. 1) and the need to keep acceleration stresses on structure and instrumentation within reason limit practical values of takeoff acceleration to 3 or 4 times g. Even so this is enough to make the gt_b term fairly small compared with the v_e's developed by modern rockets.

Thus v_o is determined primarily by the term $v_e \ln (M_0/M_e)$. Thus M_0/M_e (called the mass ratio) should be as large as possible for optimum v_e. In other words the more fuel one can carry in proportion to rocket structure plus payload the better. But even without a payload, practical engineering considerations would restrict the amount of fuel to no more than 90% of the total weight, so that at most M_0/M_e can be 10 [or $\ln (M_0/M_e) = 2.3$]. If in Eq. 1 gt_b is neglected and $v_0 = 0$, then

$$v_e \lesssim 2.3 v_e$$

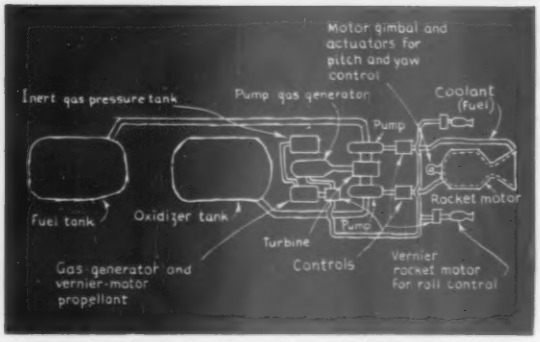
We see that, with all other factors pushed to the limit, at best v_o can be a little more than twice v_e, the effective propellant exhaust velocity. Manipulation of the parameter v_e (or its equivalent the specific impulse* $I_{sp} = v_e/g$) offers the major hope for improving rocket performance.

To good approximation v_e depends only on the combustion-chamber temperature T_c and the mean molecular weight of the propellant gas M

$$v_e = k(T_c/M)^{1/2} \text{ or } I_{sp} = \frac{k}{g_0}(T_c/M)^{1/2}$$

(k is roughly constant). Thus the ratio of chamber temperature to exhaust-gas molecular weight becomes the most significant parameter in single-stage rocket comparison; i.e., for the highest exhaust velocity (or burnout velocity), *the highest ratio of T_c/M* should generally be sought.

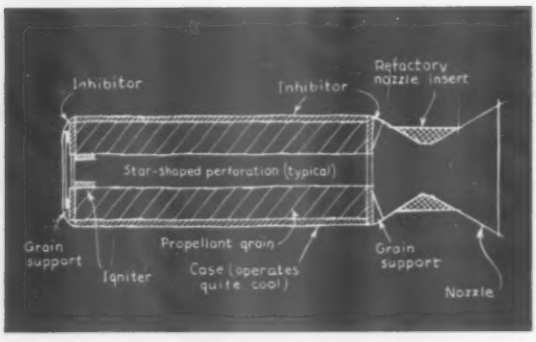
* The specific impulse I_{sp} is defined as the change in rocket momentum obtained by exhausting unit weight of propellant; thus $I_{sp} = mv_e/mg = v_e/g$.



Liquid-Propellant Chemical Rocket . . .

. . . Operates at chamber temperatures from 4,500° F to over 8,000° F, is usually cooled regeneratively by its fuel as shown. Two propellant tanks supply a liquid-line feeding and control system, major component of which is the turbopump assembly that forces the propellants under high pressure into the combustion chamber. The turbopump is powered by either hot gas bled from the rocket chamber, or, more commonly, a separate gas-generating system. The pump must operate at fantastically high power levels; for example, the comparatively tiny Atlas ICBM pump assembly requires more power than a diesel locomotive puts out.

Since the chamber temperature is fixed by the nature of the propellants and varies only slightly with mixture ratio, thrust level is controlled by propellant flow rate. The propellant injectors do not work well when throttled to pressures far from rated design conditions; hence the chamber thrust level is usually kept about constant. Startup and shutdown can, however, be accurately controlled by the feed system. Vehicle direction is maintained by gimballing the chamber to control pitch and yaw. Small exhaust nozzles or aerodynamic fins control roll.



Solid-Propellant Chemical Rocket . . .

. . . Engine contains all its propellant, called the "grain," within the combustion chamber. Different geometrical grain designs produce different thrust characteristics; e.g., the same total propellant weight can be burned in as short a time as 1–2 sec, producing very high thrust, or, by allowing only a small exposed burning surface, continue for as long as 7–8 min at low thrust. The relative simplicity and weight economy (no pumps, tanks, piping, valves, etc. are needed) give the solid-fuel rocket a high reliability and a low mass ratio, making it attractive for military use. However, solid-fuel specific impulse does not approach that of the best liquid propellants (the best reported values run around 260–270 sec compared with experimental values of close to 400 sec for oxygen-hydrogen and fluorine-hydrogen liquid rockets). Also, although the problem of accurate thrust cutoff required for ballistic missile trajectories has recently been solved, solid rockets cannot compare with liquid rockets for controllability. Further, chamber gimballing is impractical due to the large size of the propellant-filled chamber, and hence devices such as "jetevators" (deflecting rings around the exhaust nozzle) are used for directional control.

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about the disadvantages of nuclear rockets? There will certainly be problems of design and operation not found with chemical systems (see p. 66). Also, even though the nuclear rocket has a higher burnout velocity, the dead-weight penalty imposed by the reactor plus shield might conceivably cancel out this advantage. The detailed weight analysis is too complicated to present here, but a summary of the over-all results of such a calculation for single-stage rockets is shown by the solid curves in Fig. 2 (reproduced from Reference *2*). In this figure, the payload (plus instruments) weight is plotted against burnout velocity. The curves represent the "breakeven" point at which initial gross weights of nuclear and chemical vehicles are equal. Curves comparing three different nuclear and chemical propellants are shown. The region above the curve for each comparison is the field of nuclear rocket supremacy (smaller gross weight); in the region below the curve the chemical rocket is superior.

Figure 2 reveals that the nuclear rocket, even though penalized by the large dead weight of the reactor, is superior to the single-stage chemical rockets for satellite and escape missions almost regardless of payload. For the larger payloads (over 10 tons) it is superior for *all* missions.

Multistage Rockets

So far everything said applies to single-stage rockets only. The fact that man-made satellites are already orbiting over our heads is evidence that with the principle of staging rather inefficient rockets can be made to accomplish the higher velocity missions.

To illustrate this principle consider a rocket having the best operational specific impulse (about 260 sec) and the best operational mass ratio (about 9) available today. If this rocket were launched with no initial velocity v_0 (neglecting the earth's rotation), a quick calculation using Eq. 1 indicates a burnout velocity of only 18,000 fps *even when gravity and drag are neglected.* However, suppose this rocket formed the payload of a scaled-up rocket that also had a specific impulse of 260 sec and a mass ratio of 9. Then the burnout velocity of the smaller rocket (again neglecting gravity and drag for simplicity) would be

$$v_e = g_0 I_{sp} \log_e \left(\frac{M_0}{M_f}\right)_2 + v_0$$

$$= g_0 I_{sp} \left[\log_e \left(\frac{M_0}{M_f}\right)_2 + \log_e \left(\frac{M_0}{M_f}\right)_1\right]$$

$$= g_0 I_{sp} \log_e \left(\frac{M_0}{M_t}\right)^2$$

Thus, by using a two-stage rocket vehicle, the attainable burnout velocity is doubled for the example given. Although the first stage cannot achieve escape velocity on its own, it can do so when incorporated into a two-stage vehicle. [In practice, however, gravity and drag cannot be neglected. If they are included, then at least three stages (even for the best optimized combination of currently operational chemical rockets) would be needed for escape.]

It turns out that the example chosen here is the ideal condition for staging (2); i.e., the mass ratios of all stages should be the same (each succeeding stage is, of course, included as the payload of the previous one). Thus, for an n-stage rocket, the burnout velocity in a gravity-free field without drag is

$$v_e = g_0 I_{sp} \log_e (M_0/M_t)^n$$

Although staging certainly has practical importance (as evidenced by our present-day satellite and missile vehicles), a point of diminishing returns is soon reached. Consider, for example, our mass-ratio-9 rocket again. Suppose it is desired to lift a 100-pound payload (even including all dead weight) by means of an optimum three-stage design. The weight of the third stage is 900 lb, the weight of the second and third stages is at least 8,100 lb, and the weight of the whole vehicle is at least 73,000 lb.

This example, having a payload-to-gross weight ratio of $\frac{1}{730}$, is not atypical. The Explorer-I payload (including the final burned-out rocket stage) weighed only 30 lb, while the launching vehicle gross weight was over 40,000 lbs, with a resulting payload-to-gross-weight ratio of 1/1,300 and a final burnout velocity of only 26,000 fps.

Of course, this was a very inefficient four-stage design, but consider the ultrasophisticated Vanguard. The total third-stage burned-out weight of 1958-Beta satellite was about 33 lb, and the vehicle take off weight was over 20,000 lb. The payload-to-gross-weight ratio was still only about $\frac{1}{600}$, with a terminal velocity of only 27,000 fps. Thus, although staging can achieve very high velocities with low-specific-impulse fuels, it is only at the expense of adding considerable gross weight (for a given payload).

Perhaps even more important is the question of reliability. Suppose that each stage of a three-stage rocket had a 90% chance of a completely successful firing. Then the probability of a successful flight would be at most 73% less the failure probability of the stage-separation devices, or, say, about 70%. To provide the required large first-stage (and sometimes second-or-third-stage) thrusts, multiple combustion chambers in each stage are often necessary as well. The probability then of a successful flight becomes so low that the usefulness of a large, multistaged vehicle begins to look doubtful.

If we disregard the reliability problem and consider only the relative weights of optimum multistaged chemical rockets versus single-stage nuclear rockets, we obtain the comparison shown in Fig. 2 (dotted curves). Because the burnout velocity of multistage chemical systems is not limited, the advantage of the nuclear rocket, although it still exists at high payloads, is reduced below that shown by the solid curves in Fig. 2. However, the multistage reliability factor discussed above will cause the nuclear rocket to be favored more strongly than shown.

In practice the nuclear rocket might want to take advantage of some crude but reliable form of staging itself. For instance the fuel could be divided up into a number of tanks which could be jettisoned one at a time as they are emptied. Even better, one might use ultra-reliable large solid-propellant chemical boosters (similar to the JATO units that help get heavy bombers off the ground today). With such units the performance comparison with chemical multistages begins to approach the single-stage values of Fig. 2.

We conclude that the "conventional" solid-fuel nuclear rocket (and this represents only the first approach to nuclear rocket propulsion; for more advanced designs see p. 73) will outperform any liquid chemical system in carrying large payloads on high-burnout-velocity missions. Furthermore, since the single-stage nuclear rocket as currently conceived is a nonexpendable item, it can be built for continual reuse, and hence should provide a far higher degree of both reliability and cost economy than a multistaged chemical system.

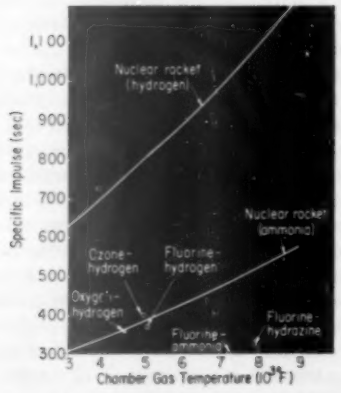

FIG. 1. Specific impulse for nuclear rocket as function of chamber temperature using hydrogen and ammonia propellants (expanded from 650 psia to 14.7 psia). Points show, for comparison, specific impulse of chemical propellant combinations at characteristic reaction temperatures and 500 psia chamber pressure

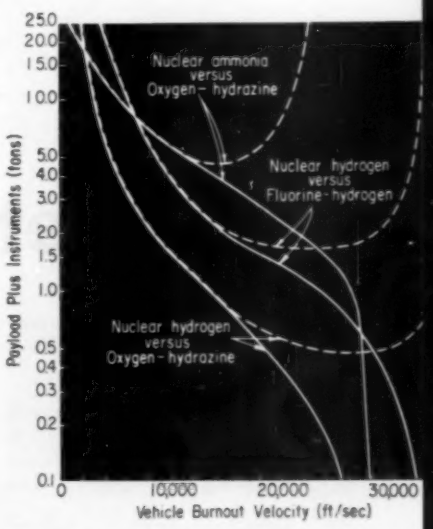

FIG. 2. Performance comparison of solid-fuel nuclear rockets (t_c = 4,500° F) with single-stage chemical rockets (solid curves) and optimized multi-stage chemical rockets (dotted curves). In each instance nuclear rocket has smaller gross weight than chemical rocket for payloads above curve and larger gross weight for payloads below curve

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Design Figures for a Nuclear Rocket Reactor

	Calder Hall	*Nuclear Rocket**
Total power [Mw(th)]	182	5×10^3–5×10^4
Core shape and dimensions	cylinder diam: 31 ft length: 21 ft	right cylinder diam: 4–8 ft length: 4–8 ft
Core power density (kw/ft³)	11.5	5×10^4–5×10^5
Mean core temperature (° F)	461	~2,000
Coolant	CO_2	H_2
Coolant flow rate (lb/sec)	1,964	500–4,000
Coolant temperature rise (° F)	353	~4,500
Coolant pressure drop through core (psi)	6	~1,000
Core lifetime	fuel: ~4 yr structure: ~20 yr	2–15 min

* Total thrust 4 to 30×10^5 lb, specific impulse ~750 sec.

Rocket-Reactor Design

By MYRON M. LEVOY and JOHN J. NEWGARD
Reaction Motors Division, Thiokol Chemical Corp., Denville, N. J.

REACTORS FOR ROCKET PROPULSION will need to operate at power densities much higher than those of conventional "earthbound" power reactors. For example, as shown in the table, one is trying to extract 100 times more power from a core that is more than 30 times smaller than Calder Hall. Correspondingly the operating temperatures will be much higher—~4,000° F, typically. Such a goal must seem completely fantastic to those acquainted with the very serious design problems involved in improving the performance of a reactor like Calder Hall a modest 10–20%.

However, although no one claims that the development of these reactors will be easy, there *are* extenuating factors. A very important consideration is the short operating life of the rocket reactor. While Calder Hall is expected to run without failures at full power for a period of years, the rocket reactor has to run at full power for periods of only a few minutes. This means rates of structural creep and corrosion and erosion of core materials that would be prohibitive in a conventional reactor could be tolerated in a rocket. Reactivity loss due to burnup and fission-product poisons would be insignificant so that any available excess reactivity could be used to compensate for the nuclear effects of corrosion-erosion.

Also the designer of a nuclear rocket reactor can afford to be much less finicky about how much radioactivity the reactor releases (as compared with ordinary power reactors). Since a nuclear rocket could be fired from an isolated site and would spend most of its operating life far above the atmosphere, a certain amount of radioactivity release could be accepted as a standard operating condition.*

In so far as the performance of ordinary reactors is limited more by considerations of safety than by the possibility of gross structural failure, this gives nuclear rockets additional edge.

Reactor Type

For the first attempt at building a working nuclear rocket, a straightforward solid-fuel-element reactor design (see Fig. 1) in which H_2 gas is heated as the propellant (much like the coolant in an ordinary reactor) seems the wisest choice. Although such a scheme appears unimaginative when compared with other possibilities (see p. 73) it is one that we have confidence that we can build today.

The first step is to decide what available materials have the desired nuclear properties and also have a chance of standing up under the extreme operating conditions of high temperature, high gas flow and high acceleration loads. If we think in terms of a thermal or epithermal reactor system then choice of core materials is limited to ceramics such as graphite, BeO, and carbides, which are good moderators, and to a few good moderating metals such as Be. In terms of high-temperature strength, resistance to H_2 and neutron absorption, graphite seems to be the best of these materials for temperatures of 4,000°–5,000° F. Also, the high-temperature values of the quantity* $E\alpha/k$ for graphite are low compared with the other ceramics, which means that lower thermal stresses occur in graphite than

* From a world-wide viewpoint, any contamination would be negligible. At burnout the core of a reasonably sized rocket reactor would contain in total less than a few per cent of the fission products released by a 20 kiloton atomic bomb. Since even under the worst conditions only a small fraction of these products would actually escape, the total contamination should be insignificant compared with an atomic bomb.

* E is Young's modulus, α is the coefficient of thermal expansion and k is thermal conductivity.

in other ceramics. In addition, graphite's thermal conductivity is quite good compared with other ceramics, permitting higher exit gas temperatures for a given fuel-element thickness or diameter.

A fast reactor, on the other hand, might appear to be better since no space is wasted on moderator or reflector. However, the structural-material choice here is even more limited; tungsten is one of the few high-temperature, moderating materials available. Also, for safety, fast-reactor excess reactivity has to be kept less than $1.00. Since considerable excess reactivity may be needed to compensate losses of core material during operation, a reactor system with enough thermal neutrons to give a reasonable excess reactivity seems like the best approach and is the one we will discuss from here on.

Fuel-Element Design

Developing a satisfactory fuel element is first on the list of problems. One starts with one of the high-temperature materials such as graphite as combination moderator and matrix for the uranium fuel. Then it is necessary to fabricate this mixture into shapes rugged enough to withstand violent thermal and mechanical stresses and yet thin enough to minimize thermal gradients and provide adequate surface area. Some possible fuel element shapes are shown in Fig. 2. With other things equal the design with the smallest pressure drop is preferred.

A comparison study of the elements in Fig. 2 indicates the superiority of sandwich or plate-type fuel elements and rod-type elements. In this study, all factors were held constant except element shape. Element sizes were determined by temperature and stress limitations. The greater fuel-bundle complexity and greater propellant-flow blockage (with spacers) for rod elements make parallel plate elements the more desirable of the two. The plates could be bound together at several points by drawn tungsten or molybdenum wire. Conceivably the elements might be used unclad; alternatively, a ceramic coating could be developed. Plate element thickness is limited on the high side by thermal stress and absolute temperature limits and on the low side by fabrication and rigidity problems. Between 0.030–0.125 in. is a likely thickness range.

Core Design

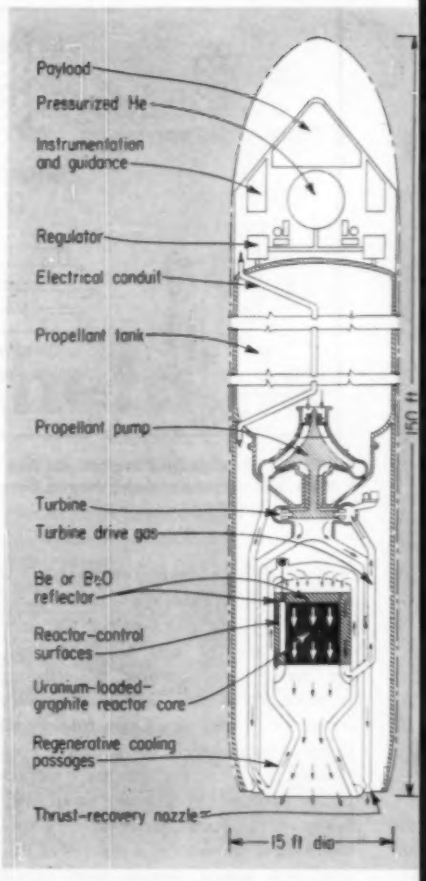
Once the decision has been made to use, say, graphite-plate-element bundles, the next problem is to hold the bundles together into a compact, rigid core. The assembly must bear up under a 4,500° F axial temperature difference, a 1,000 psi pressure drop and 10 g accelerations and at the same time be as small and light as possible. Again graphite appears to be a good possibility for the structural material.

One possible scheme would use a matrix of lateral beams and cross braces to secure the fuel-element bundles in place. The matrix would transfer the pressure-drop load to metallic tubular tension columns (which are supported from the cold end and run the length of the core) and to the rocket outer wall. The tension columns would be cooled with liquid hydrogen flowing internally and would be made of a high-temperature metal like molybdenum. The total amount of such material would have to be kept small for a reasonable critical mass (see Fig. 3).

An alternative all-graphite structure might use a compression arch at the hot end of the core to support the core matrix. This scheme would take full advantage of graphite's superior strength in compression but would be harder to build than the first one.

An additional worry in laying out the core is that nonuniform coolant-space and fuel-density distributions are required for optimum performance. For instance, a design using a constant void fraction through the core (void fraction = flow area/total area) would give an almost exponential increase in pressure drop Δp as the gas approaches the hot end of the reactor. A better design would use a variable void fraction through the core to reduce the over-all pressure drop* across the core preferably without introducing much additional fabrication difficulty. A saving in core structural weight might also result due to the lower dynamic forces.

Similarly, to squeeze as much power as possible from the temperature-limited core the fuel distribution would be varied in both the radial and axial directions to keep the peak-to-average temperature ratio to an absolute minimum.



NUCLEAR ROCKET FLOW SCHEME. Liquid hydrogen is stored in insulated tanks equipped with "blow-off" valves that relieve excessive pressure. Pressurized helium replaces hydrogen as it is drawn off to propellant turbopump. Hydrogen at high pressure (~10^3 psia) flows from pump through ducts to exit end of rocket nozzle where it is used to cool nozzle and reactor chamber walls before entering plenum. Most of hydrogen then flows down through reactor and out DeLaval nozzle at 4,000° F. Small amount of hydrogen is diverted at plenum to cool reflector and structural columns. Gas leaving reflector at 1,500° F and 350 psia is used to drive turbine of turbopump. Bypass valve affords turbine control. Turbine exhaust gas is expelled through thrust-recovery auxiliary nozzles (FIG. 1)

Reactor Control

The main function of the reflector would be to act as a variable source of thermal neutrons for reactor control. Figure 3 shows the large reactivity

* By proper distribution of void space the decrease in pressure drop attained at the hot end is much greater than the increase at the cold end and hence the integrated pressure drop is lower than for the "exponential" case of constant void fraction.

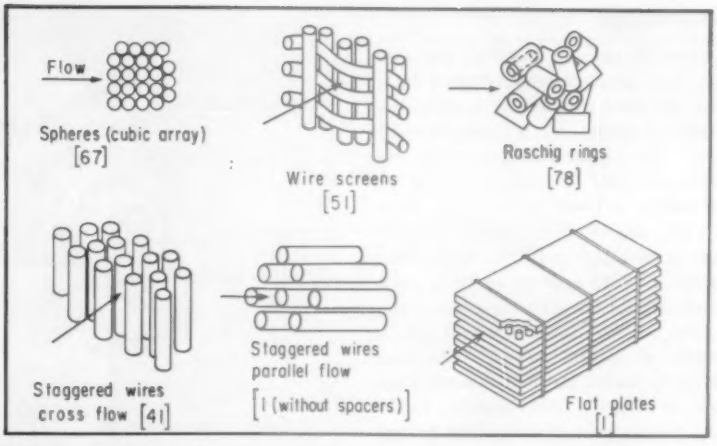


FIG. 2. Possible graphite fuel-element configurations. Studies of relative pressure drop (numbers in brackets) showed flat plates and staggered wires with parallel flow to be superior

controlled by reflector changes. For example, the critical mass varies more than a factor of two between the fully reflected reactor and the bare one. By using some scheme of reflector poisoning this large excess reactivity could be made available for operational needs, which, as we have seen before, may be considerable. Reflector control would also do away with many of the problems of putting control rods in the core of a reactor of this kind and would provide more excess reactivity.

The reflector-poison control elements could be in the form of long boron plates stationed within the reflector around the reactor core and reaching the length of the core. The plates would be rotated in circular slots by a mechanical drive system so that they could be moved from the inner to the outer boundary of the reflector. With the plates turned in, the reflector would send back very few neutrons to the core; with the plates turned all the way out the maximum number of neutrons would be returned.

During startup, reactor power and fuel flow would be carefully synchronized to establish the final steady-state temperature distribution throughout the core at low power. Power and flow would then be pushed up to their full design values while preserving the temperature distribution. The first step would be carried out slowly to minimize thermal stresses; the second step must be done as rapidly as possible to conserve propellant. An extremely sensitive and reliable reactor-turbopump control system will be needed to carry out these steps.

During power operation (perhaps sooner) various reactivity changes will occur due to changes in the material composition of the core. Some changes to consider include:

(1) Reactivity change due to change in hydrogen density in the core void volume.

(2) Uniform decrease in the solid volume of the core (including both fuel and moderator) due to corrosion-erosion.

(3) Nonuniform decrease due to destruction of a plate or bundle in the core matrix and its consequent discharge out of the core by the propellant gases.

Nonnuclear Components

Nozzle design. The design of the ejection nozzle for the hot gas is based on the same principles as those used in chemical-rocket nozzle design. A converging-diverging nozzle (DeLaval nozzle) is used to reach the supersonic exhaust velocities necessary for high thrust.

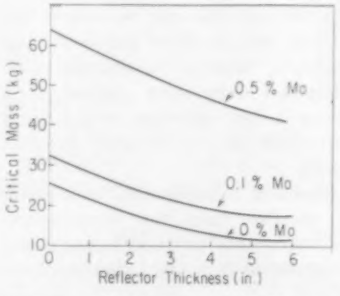


FIG. 3. Critical mass of highly enriched U as function of BeO reflector thickness for epithermal rocket reactor. Three curves refer to different concentrations of molybdenum in U-graphite core 5 ft in diam and 5 ft long

As in chemical rockets, the major problem in the nozzle design is keeping temperatures below the maximum allowable in the nozzle wall. A common procedure is to cool the nozzle and chamber walls regeneratively. In this case, the main propellant (or a portion of it) is first pumped through coolant passages around the chamber and nozzle after which this preheated fluid is sent through the chamber. Cryogenic hydrogen does not present insuperable difficulties for this application.

In chemical rockets, the greatest heating problem occurs in the converging portion of the throat due to the high velocity-temperature combination at that point. The same is true in the nuclear rocket, with the additional problem of gamma-ray heating from the reactor. Since the converging section of the nozzle is relatively close to the reactor and since the converging section "sees" the reactor, gamma heating is particularly serious here. Nevertheless, it appears possible to overcome the problem with regenerative cooling.

Chamber design. In the chamber design a very considerable axial force from *g*-load and drag is transmitted to the shell from the reactor core via the structural support members. This is in addition to the usual hoop stresses due to gas pressure. A relatively heavy wall is therefore necessary in the chamber. But heavy walls not only decrease over-all rocket performance due to greater weight; they also lead to higher wall temperatures and thermal stresses because of heating by leakage gamma rays. (The gas-cooled reflector will help decrease the gamma-ray intensity to some extent.) As with the nozzle the hydrogen propellant appears to be satisfactory as a coolant for the reactor chamber.

* * *

We gratefully acknowledge the contributions of Mr. John Giovannucci for the reactivity analysis performed utilizing a modified perturbation theory he devised. Mr. Robert Behnke and Mrs. Arlene Pollack performed many of the numerous calculations in the nuclear and engineering analysis which led to the systems described in this paper.

1946—First Nuclear Rocket Proposal; Scheme Shelved

1955—Decision to Sponsor Study Program

1957—Four Programs Acknowledged:

Rover—Nuclear rocket

Pluto—Nuclear ramjet

Snap—Auxiliary nuclear power for satellites

Ionic Propulsion—Advanced propulsion system

1958—First Test of Nuclear Rocket Reactor

1959–60—Choose Reactor for First Nuclear Rocket

1965–1970—First Nuclear Rocket Flight

Nuclear-Rocket Timetable

To GET its first nuclear rocket into the air by 1965, the United States would have to decide this year what hardware it would take to get it built. Such a decision is at least a year away—maybe two—and the rocket itself is almost ten years off.

This is the feet-on-the-ground view of Col. Jack Armstrong of the U.S. Air Force and Atomic Energy Commission, who, from his desk at AEC headquarters, is directing the effort to perfect a nuclear rocket engine.

Colonel Armstrong points out that the propulsion phase of nuclear rocketry represents the major problem, indicates that several systems must be tested before any can be selected, and concludes that a "crash" effort to secure an over-all rocket system cannot go ahead until a workable rocket engine is demonstrated.

"I think we will be getting some answers in the next two years. At some logical point in the next couple of years we should have a pretty good feeling . . . for increasing our effort," he told NUCLEONICS.

The first serious study of nuclear rocketry was undertaken in 1946; it produced no program. Three years ago, the Air Force and AEC took another look and decided to revive the scheme. As a result, the first reactor designed specifically for rocket use is scheduled for completion at Jackass Flats, Nev., this fall (see p. 70).

The government effort to this point has been relatively small in terms of both money and manpower; moreover, it is primarily a military effort and will remain so until formation of the proposed National Astronautics and Space Administration, which is now under debate in Congress.

Armstrong feels it will take "billions of dollars" to reach the rocket shooting stage. By way of contrast, spending to date has been something less than $25-million for Projects Rover (rocket) and Pluto (ramjet) and some $30–35 million has been requested for the fiscal year which began July 1, 1958. Because operating expenses are classified, these figures reflect construction spending only. For fiscal '59 they include a $25-million boost which will permit two years' work in one.

The organizational setup is this: AEC is charged with reactor development; the Air Force, through its Wright Air Development Center, with nonnuclear aspects. AEC has two prime contractors: Los Alamos Laboratory for Rover, and Livermore Radiation Laboratory for Pluto (though the rocket and ramjet programs are separate they overlap in the sense that both involve development of extremely high-temperature reactor systems).

Major contractors in the Rover program are North American Aviation's Rocketdyne Division and Aerojet General (both working on fuel and reactor materials and nonnuclear components like pumps, etc.), ACF-Erco (pressure shell), and Edgerton, Germeshausen and Greer (instrumentation). In addition there are a dozen or more small contractors.

Work on the ramjet program has also reached the point where the first test facilities will be ready this fall; they, too, are under construction at the Jackass Flats site. Pluto contractors include Atomics International (reactor materials), Marquardt Aircraft (nonnuclear components), Curtiss-Wright (components for the test facilities) and M & C Nuclear (fuel elements).

Outside of the government's program, Armstrong reports evidence of interest in nuclear rocketry from every major aircraft-engine and -frame firm in the country. A NUCLEONICS survey turned up this list of firms with active programs: General Electric, Northrop Aircraft, Bendix Aviation, Lockheed Missile Systems, General Dynamics, Martin and Ramo-Wooldridge.

Progress Abroad

As with most other technological advances of military value in the past 10–15 years, the race to develop nuclear rocket propulsion is one between the U. S. and Russia.

Russia's program is the usual mystery. However, as early as 1954 Russian scientists were talking about the "tremendous importance" of atomic energy to the development of space rockets, and as recently as late 1957 Russia's Military Press published a 184-page primer on the application of nuclear propulsion to rockets and aircraft (available in English translation from Technical Information Service, Oak Ridge, Tennessee). The document reflects thinking like that in the U. S. on the need for moving ahead with chemically-fueled rockets pending development of nuclear propulsion and the likelihood that interplanetary travel will depend on nuclear and more advanced concepts like ion and photon propulsion.

"At present," it says, "thanks to the progress made in nuclear physics, to the development of a rapidly progressing science of atomic power and to the creation of an atomic industry, we have come close to the solution of the program of making use of atomic energy in rocket engineering."

Los Alamos' Project Rover

By RAEMER E. SCHREIBER
Los Alamos Scientific Laboratory, Los Alamos, New Mexico

WORK on nuclear rocket propulsion has been underway at the Los Alamos Scientific Laboratory (LASL) for about three years under the code name Project Rover. The first experimental test device, known as Kiwi-A, is scheduled for operation at the USAEC Nevada Test Site late this year with testing activities expected to extend into 1959. The reference to the flightless New Zealand bird gives a clue to the purpose of the Kiwi-A test device—it is an experimental reactor that is not expected to fly and does not necessarily have flyable characteristics.

Kiwi is but a part of an over-all nuclear rocket development program designed to provide a broad technical foundation for nuclear rocket designers. Design comparisons (see p. 62) have shown that even the relatively unsophisticated solid-fuel-reactor rocket system compares favorably with the best that chemical systems can do. The same studies, however, always run up against uncertainties in solid-reactor-material temperature limitations and convective heat transfer. A large part of Project Rover is dedicated to removing these uncertainties.

Program Scope

Both the LASL and the Livermore Laboratory of the University of California Radiation Laboratory took part in initial studies three years ago. Subsequently, the Livermore effort was redirected to nuclear ramjet development (Project Pluto). Prior to the start of the Rover program the known work on nuclear rocket propulsion had consisted only of some general studies and the preliminary evaluation of selected high-temperature reactor materials. There was no backlog of basic information to serve as a foundation for specific hardware development. This lack was particularly apparent in the fields of high-temperature chemistry and physics and in the practical knowledge of the physical properties of materials at elevated temperature. Rather than devote several years to general investigations of these fields, the decision was made to combine a limited amount of general research with specific development programs and to make the design, fabrication and operation of experimental reactors a part of the development program. The Kiwi-A test device is the first of these experimental reactors.

Reactor Testing

The problem of reactor control differs from conventional power reactors since the high power density and large range of operating temperature demand large rapid changes in reactivity. The control system therefore requires a thorough understanding of the dynamic performance of the entire engine. Studies have included calculations involving both digital and analog computers. The reactor control system itself must include a fairly complex analog computer that receives information on temperature, power level and propellant flow rate, compares these with the desired conditions and transmits command corrections to the power-plant controls.

The complete reactor design must be compatible with the available materials and the neutronic requirements and must be controllable over a wide power range. The structural and thermal stress loads and the hydrodynamic flow of any fluids in the reactor must be understood both for the planned operating conditions and the excursions involved in the starting and stopping procedures. Component tests offer partial information on many of these topics, but an integral test of an operating reactor is an essential part of the development program. The information generated from such a test is not necessarily limited to the test results, since the undertaking of a specific development is a powerful tool for exposing problems that are passed over lightly in paper studies.

Because of the potential hazard involved, the Rover reactors cannot be operated at power at Los Alamos and

FIG. 2. Submarine battery installation supplies 1 Mw power for Project Rover material and component tests

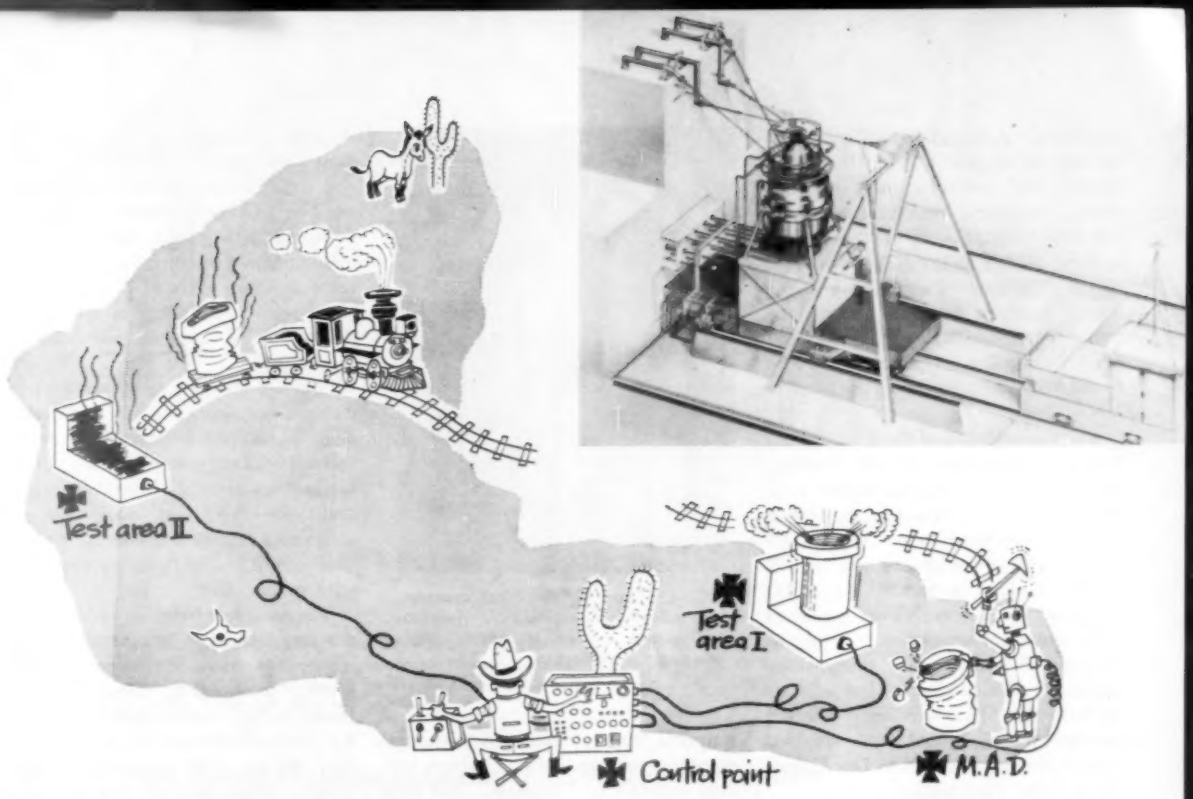


FIG. 1. Project Rover facilities now under construction at Jackass Flats near Mercury, Nevada will include test cells linked to maintenance, assembly and disassembly (MAD) facility by remotely controlled locomotive. Insert pictures Kiwi-A—project's first test reactor—installed on test stand. First test is scheduled for fall of this year

will be tested in the AEC Nevada Test Site located approximately 100 miles northwest of Las Vegas. A new test area is being developed about 20 miles west of the base camp at Mercury in a location known (inappropriately, one hopes) as Jackass Flats. The general site layout is shown in Fig. 1. The three areas now being completed are the Control Point, the Maintenance, Assembly and Disassembly (MAD) area and Test Area I. These are separated by distances of 1½–2 miles. The MAD area has facilities for the assembly and instrumentation of the test device and a shielded laboratory for the remote disassembly and inspection of the hot reactor after it has been run. The assembled reactor on its test car is moved over railroad trackage to the Test Area I where it is attached to the test cell.

The insert in Fig. 1 shows the Kiwi-A test reactor installation. It can be seen that the reactor is unshielded, that it fires upward and is mounted on a test car to permit its return by the remotely operated prime mover after operation. Control and instrumentation leads pass through a shielding plug into the concrete test cell. Adequate shielding is provided for entry into the test cell for maintenance operations after a cycle of reactor operation but no personnel will be permitted in this area during the actual hot operations.

High radiation levels will exist near the reactor during its operation and there will be induced activity due to neutron capture by nearby materials in addition to the residual activity in the reactor itself. These factors have been taken into account in the design of the test stand and the arrangement of the equipment. After a relatively low level of operation, it will not be possible to approach the reactor. To the extent possible, all equipment and instrumentation is located within the shielded test cell in order to permit repairs or calibration between hot runs. At least for Kiwi-A, failure of any essential component not accessible inside the test cell will terminate the test. Consideration was given to remote repair of external items, but it was believed to be unfeasible within the time scale desired for this first integral test.

Since the reactor operates on an open cycle—that is, the propellant or coolant is discharged to the atmosphere—there is also a high probability of contaminating the local area with fission products. Operations can be conducted therefore only under wind conditions that carry contamination away from the propellant tank farm and distribution bunker. It should be noted that a complete release of all fission products cannot contribute significantly to the world fallout. The energy release for the entire Kiwi-A operations is equivalent only to a bomb yield of a small fraction of a kiloton. The experience and facilities of the AEC that have been developed in connection with the nuclear bomb testing at the Nevada Test Site will be utilized to measure the local contamination and to take the necessary precautions against radiation health hazards.

The remote control and instrumentation for the Kiwi-A reactor requires that several hundred signals be transmitted between the control building and the test area. These are carried by direct burial cables. In general, all signals are converted to a standard range of voltages by means of line driver

amplifiers. Although complicated by the number of circuits, the data transmission and recording uses conventional techniques. Information essential to the operation of the test device is displayed on monitoring panels and the key information concerning power level, propellant flow rate and reactor temperature is displayed before the master controller. Operations may be conducted manually or by automatic sequencing.

Upon completion of the Kiwi-A test, remotely operating devices separate the reactor and its mobile test car from the test cell. A remotely controlled prime mover then moves to the test cell, couples to the test car and hauls it to the shielded portion of the MAD building. Disassembly is accomplished with remote manipulators. A limited amount of post mortem examination can be performed in small hot cells attached to the MAD building. Selected specimens are loaded into shielded containers and returned to Los Alamos for detailed examination.

Supporting Facilities

The Rover program requires talents and facilities including high-temperature research, chemical and metallurgical research, fluid dynamics, neutronics, control analysis and mechanical design. Very high temperatures and high heat fluxes are required if interesting rocket performance is to be attained. Most of the materials of interest must have melting points above 2,000° C and one would like to know the physical and chemical properties of such materials over a wide range of temperatures. Obvious choices of materials are the refractory metals such as tungsten, molybdenum and tantalum; graphite, various metallic oxides, borides, carbides and nitrates. For fuel-element development, it is also necessary to know how the compounds of the fissionable elements can be combined with structural or dispersing materials and how these mixtures behave under reactor operating conditions.

FIG. 4. "Aunt Polly" critical assembly uses polyethylene moderator. Test materials are loaded in vertical tubes piercing the moderator

To know the basic properties of the reactor materials is not sufficient. The program must include the ability to fabricate the materials into the required shapes and the limited production capability required to manufacture experimental reactors. Finally, the reactor does not simply sit and glow quietly, it must be giving up its heat to a propellant which is roaring through the reactor at high pressures and velocities. Studies of corrosion, erosion, high-temperature reaction rates and thermal and mechanical stresses are a part of the development effort.

Although excellent chemical and metallurgical research and development facilities exist at Los Alamos a substantial investment in specialized equipment has been necessary for the Rover program (see Fig. 2). Typical equipment includes resistance and induction furnaces, molding and extrusion presses, powder-metallurgy equipment, high-temperature equipment for the measurement of physical properties and specialized test equipment for subjecting reactor components to suitable conditions of temperature, pressure and gas flow.

The neutronic behavior of propulsion reactors is studied by the usual techniques of reactor physics. Multigroup, multiregion calculations are made on high-speed digital computers for idealized systems to guide the general design. The experimental work ranges from general studies using approximate geometry to detailed control and power distribution studies using the actual test reactors. One of the critical facilities used is a "Honeycomb" geometry-type (see Fig. 3) made up of stacked square Al tubing which can be filled with various reactor materials. One half of the structure is mounted on a cart that can be moved remotely to complete the assembly. The Honeycomb machine is used to conduct measurements of critical mass as a function of geometry and materials, and for flux mapping and power distribution studies. Figure 4 shows another critical facility employed in the program which uses polyethlene as a moderator.

The development of the Kiwi-A test device has demonstrated the importance of carrying out detailed experiments in arriving at the basic reactor design. Although theoretical calculations are important in establishing the essential relationships between fuel loading, moderator and reflector parameters, they sometimes fall flat in coping with the engineering features demanded of a practical reactor. In the Kiwi-A development, for example the reactor fuel volume was drastically increased in going from the idealized case to the final design. More than a dozen separate critical assembly experiments were required to develop the reactor configuration finally chosen.

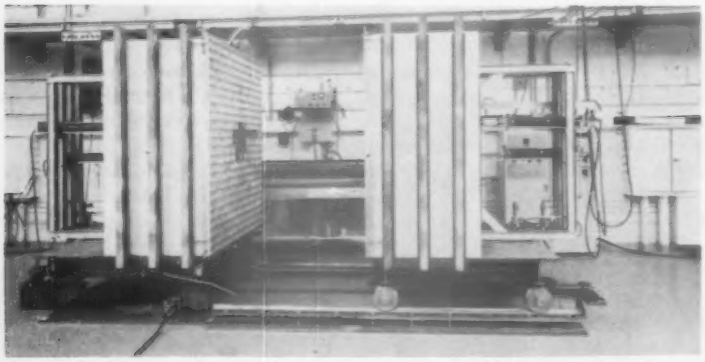
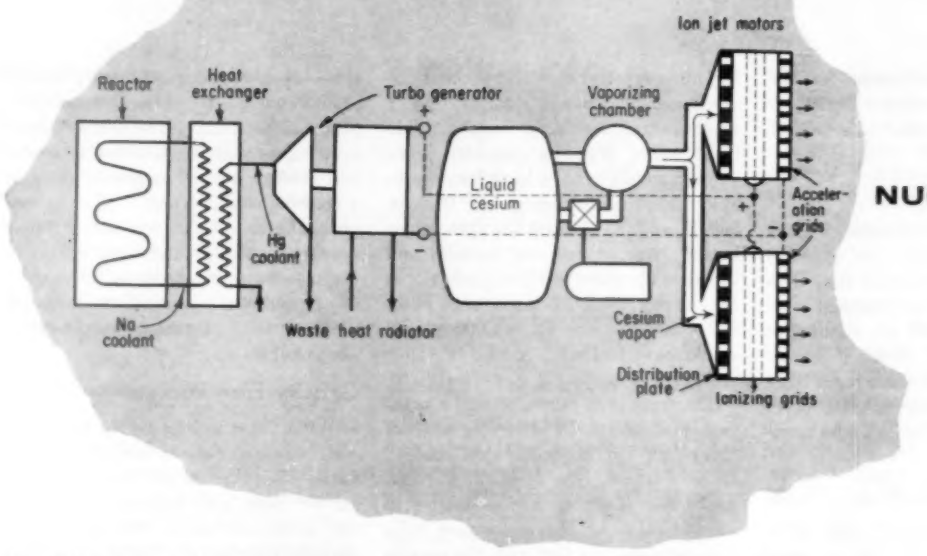


FIG. 3. "Honeycomb" critical assembly is operated remotely to measure critical masses and map flux and power distributions for rocket reactor studies



ION ROCKET may satisfy need for high specific-impulse rocket for interplanetary travel in gravity-free space. Here nuclear-reactor-turbogenerator combination supplies voltage to cesium-ion accelerator. Thrust per lb of fuel would be 50 times that of present day rockets. (After M. I. Willinski and E. C. Orr, "Project Snooper") FIG. 1.

Fission Gases, Fusion Plasmas or Cesium Ions Will Power Rockets . . .

Beyond Tomorrow

To TRAVEL VERY FAR in space, say to the planets or beyond, men will have to invent rockets that have orders-of-magnitude better performance than the chemical or first-generation-nuclear systems discussed on p. 62. The specific impulse of these "present-day" systems is limited, finally, by the energy of the molecular bond. For chemical rockets this limitation appears in the peak gas temperatures that can be achieved by combustion processes. For nuclear-heated rocket motors, the limitation is the molecular-structural failure points of the various materials. Unfortunately the best structural materials are limited to temperatures of about 5,000°–6,000° F (about 0.25 ev). The temperature limitation on the fission process itself, however, is roughly the kinetic energy of the fission fragments, which corresponds to about 10^{12}° F. Since higher temperatures are vital to rocket performance (see p. 63), any scheme that promises to circumvent the molecular-bond limitation to take advantage of the high temperatures inherent in nuclear energy sources deserves serious attention. Some schemes that have been proposed include: a reactor with fissionable fuel in gaseous form, devices that use the fusion reactions as energy sources and systems that use electric fields to accelerate charged particles for thrust (see Fig. 1).

Although today none of these proposals has yet gotten to the hardware stage, we can be certain that some of them will eventually provide the means for serious space travel. An important bottleneck to be broken for many of the devices is the development of an efficient, light-weight scheme for converting heat to electricity.

Gaseous Reactors

The way to avoid structural-material temperature limitations in a fissioned-powered rocket is to arrange things so that the fission fragments transfer their energy directly to the hydrogen propellant rather than through an intermediate fuel-element structure. For instance, the uranium might be made thin enough so that the fission recoils escape and heat the hydrogen directly. A more ambitious—but in the long run more promising—design would be a gaseous-core reactor—one in which the critical mass is intimately mixed in a gaseous state with the propellant (*1*). Since the heat is produced internally in the gas, the gas temperature could be much higher than the temperature of the surrounding containment structure. The difficulty with the scheme is that some fissionable material will inevitably be lost to the propellant exhaust stream. The question is whether the total amount of fissionable material that escapes in providing the impulse needed for practical missions is within reason. Another way of saying this is that the specific impulse of the exhaust stream must be high enough to compensate for the cost of the material exhausted. The specific impulse I_{sp} and the amount of fissionable material lost W_{fuel} are directly related to the chamber pressure P_c by

$$P_c = [g(\gamma - 1)/2\gamma] I_{sp} I_{tot} \rho_{fuel} / W_{fuel} \quad (1)$$

With reasonable estimates for the specific heat ratio γ and the density of fuel in the gas chamber ρ_{fuel}, Eq. 1 becomes

$$P_c = 4.5 \times 10^{-3} I_{sp} I_{tot} / W_{fuel} \quad (2)$$

where I_{tot} is the total impulse, W_{fuel} is the weight of fissionable fuel expelled and P_c is in psi. Suppose that in a nuclear rocket we were satisfied with a specific impulse of 300 sec, about that obtained in modern chemical rocket engines. A typical mission for a large rocket would require a 100,000-lb thrust for about 150 sec. These numbers give

$$P_c = 2 \times 10^7 / W_{fuel} \quad (3)$$

If a system pressure of 1,000 psi is used (which is high by conventional standards) the total amount of fissionable material expelled would come to 20,000 lb. In terms of money this would be equivalent to throwing away about $150 million per launching, which is clearly impractical. For a more reasonable fuel expenditure, say 300 lb, the system pressure would have to be 60,000 psi—way beyond the limits of any conceivable structural material.

A way to get around these gaseous-reactor difficulties would be to provide a mechanism that prevents the fissionable-material gas particles from being exhausted along with the propellant. The effectiveness of such a mechanism could be expressed as the ratio S of the fuel mass expelled with and without the mechanism. S would enter into Eq. 1 as a multiplying factor on the right-hand side. We can consider what value S would have to have for reasonable rocket performance. If W_{fuel} = 300 lb and I_s = 3,000 sec (ten times better than conventional rockets) and if we use the same total impulse (1.5×10^7 lb sec) previously used, then $P_c = 6.7 \times 10^5 S$. For P_c = 1,000 psi, S would have to be 1.5×10^{-3} or 1:670 fuel-mass separation.

The trick is of course to find a practical mechanism for achieving an S of this size. This no one has yet claimed to have done. The mechanism could make use of either the difference in atomic mass or charge-to-mass ratio e/m between the fuel and the propellant. An example of the first would be to rotate the gases very rapidly so that the heavier atoms would be forced to the outside and could be siphoned off before they were lost in the exhaust. Electric or magnetic fields could be used to exploit the difference in e/m. This would be made possible by operating at a temperature high enough to ionize the gas.

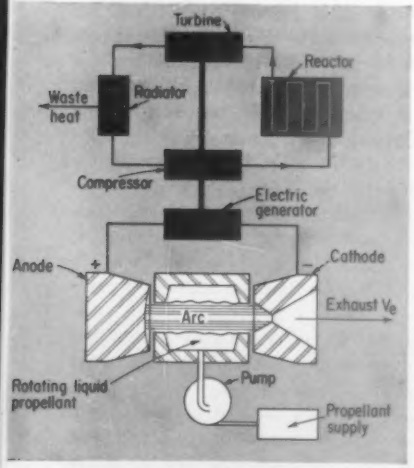


FIG. 2. D-c arc down center of rapidly rotating cylinder of liquid propellant ionizes vaporized propellant and exhausts it through hole in cathode at temperatures as high as $10^{5\circ}$ F

Fusion Propulsion

The idea of controlling an ionized gas with magnetic fields suggests using a fusion reaction in the propellant gas itself to provide thrust. The usual picture of a fusion device—a high-temperature plasma ($10^{8\circ}$ K) isolated in space by magnetic field lines—seems to adapt itself quite easily to use as a rocket motor. Also, compared with a gaseous fission reactor, a fusion device would produce no radioactive fission products and its configeration is not constrained by the need for a critical mass. The most likely fuel would be liquid deuterium which undergoes these fusion reactions

$$D + D \rightarrow T + p + 4 \text{ Mev}$$
$$D + D \rightarrow He^3 + n + 3.2 \text{ Mev}$$

If the deuterium gas and its reaction products could be exhausted at the reaction temperature of $10^{8\circ}$ K (10 kev), this would give an effective specific impulse of about 10^5 sec. For the 1.5×10^7 lb-sec mission mentioned above the total weight of D_2 needed would be roughly 1,500 lb. With D_2O selling at $20/lb the total cost of the D_2 fuel would be $150,000.

The problems of developing a fusion rocket motor are largely the same as those of developing stationary power plants using the fusion reaction—practical ways have to be found to heat up the gas to the reaction temperatures and confine it with magnetic fields in a stable configeration. After these problems are solved for devices that operate on the ground then work can begin in earnest to reduce the weight of propulsion versions to a point where useful thrust-to-weight-ratios are possible.

Gravity-Free Rockets

What constitutes a useful thrust-to-weight ratio for the rocket motor of the future deserves some comment. So far we have been talking in terms of the prime movers of the space era—rockets capable of lifting a payload from the earth's surface into an orbit or past the escape velocity. Motors for these rockets must provide a thrust-to-weight ratio (for the rocket as a whole) of at least unity and preferably much larger.

When interplanetary explorations come into vogue, there will be a requirement for a new type of rocket motor than can squeeze large amounts of impulse from modest amounts of propellant for travel over the huge distances of the solar system. Since this rocket motor will be operating in gravity-free space, the thrust-to-weight ratio can be very small compared to unity. Instead of 2 or 3 lb of thrust/lb of mass such rockets might produce 10^{-3} lb of thrust/lb. However, this acceleration would be applied over a period of months rather than seconds so that the final velocity of the gravity-free rocket could be many times the burnout velocity of the escape vehicle that launched it.

The low thrust-to-weight ratio means that designers can afford to incorporate relatively heavy equipment and machinery to exhaust small amounts of propellant at very high energies. In this way high velocities and large total impulse can be achieved with the use of a minimum of propellant.

A fusion reactor would seem to be a good candidate for this application. The equipment needed to generate the magnetic field that confines the plasma might be accommodated in a gravity-free rocket even though it proves too heavy for the ordinary kind of rocket.

Another scheme would heat the propellant gas in an electrical-arc discharge. The electrical energy would

be produced by a more-or-less conventional turbo-generator set powered by a reactor, or, possibly, by more direct thermoelectric conversion methods when they become practical. Experimental work on high temperature stabilized arcs in Russia (*2*) and Germany (*3*) shows that temperature is limited (by radiation losses to the container walls) to about 10^{5}° K. Figure 2 shows one way of getting thrust from an arc discharge.

Ion Propulsion

To get still more efficient thrust one could apply electric or magnetic fields to accelerate propellant ions directly to high exhaust velocities. Particle accelerators of this kind have been frequently proposed (*1*, *4–7*) as gravity-free vehicles. A typical scheme (see Fig. 1) would use a simple arrangement of electrostatic accelerator grids to accelerate the propellant ions. The propellant could be carried in either solid, liquid or gaseous form and would be fed into an ionizer that supplies the accelerator grid system. The ionizing mechanism could be an electric arc or heated metallic plate. A reactor-powered turbogenerator set would supply electrical energy to both the accelerating grids and the ionizer.

As with all the devices that convert thermal energy into electrical energy, the major design problem is to make the weight-to-power ratio small enough to give a useable thrust-to-weight ratio. Bussard and DeLauer (*8*) have made estimates of the weight-to-power ratio for an ion-propulsion rocket using conventional reactor-turbogenerator equipment.* They arrive at a value of 4,800 kg/Mw(e) (including the allowances for a waste-heat radiator and secondary heat exchanger but not including the weights of fuel, fuel tankage, instruments and payload.)

For a given weight-to-power ratio the specific impulse is improved by using ions with very high molecular weight. This is true because a heavy ion has less kinetic energy than a light ion of the same momentum; thus less power is needed to supply a given specific impulse if heavier ions are used. For convenience the fuel material should also be easy to ionize. For these reasons, cesium, which has an atomic weight of 133 and an ionization energy of 4 ev is often mentioned as a possible propellant.

The value of the accelerating voltage is another factor influencing the power requirements. For voltages below 5 kv, most of the ions are deflected so that they strike the negative accelerating grid resulting in a small ratio of ion-exhaust current to accelerating-grid current (which means power is being wasted). As the voltage is increased more ions are able to miss the grid and the ion-to-grid current ratio rises. Experiments (*7*) show that this ratio levels off at its maximum value for voltages above 12 kv. Since kinetic energy increases as the square of velocity while momentum goes as only the first power of velocity, there is little incentive, from a power consumption viewpoint, to increase the voltage much further than this. Somewhere around 12 kv then seems to be an optimum value for the accelerating voltage. For cesium ions this corresponds to an ion exhaust velocity of the order of 5×10^{5} fps or a specific impulse of 15,000 sec (about 50 times that of the best chemical fuels today).

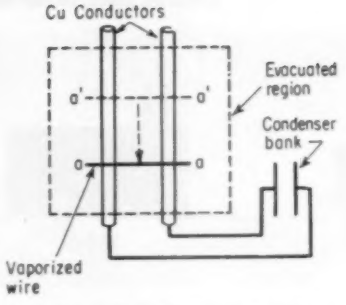
With the thermoelectric power sources available today, these considerations add up to a propulsion device with a thrust-to-weight ratio limited to about 10^{-4}. If we envision a rocket with gross weight of 10^{5} lb, this would mean a total thrust of ten lb. The required mass-flow-rate of cesium ions (at 12 kv accelerating voltage) would be 7×10^{-4} lb/sec. Relationships developed by Boden (*7*) show that 5 Mw of electric power would be needed; this would indicate a reactor power source in the 20-Mw class.

The total thrust (here 10 lb) fixes the electric field volume (grid area times voltage gap) of the accelerator grid system. For a reasonable grid area of say 10 ft² and for an accelerating voltage of 12 kv, the voltage gap must be 0.25 in.

Half of the rocket's gross weight would be taken up by the power and thrust generating equipment. Suppose that of the remaining 25 tons, two thirds is devoted to fuel (plus tankage) and one third to instruments and payload. This gives a mass ratio of 1.5 so that (from Eq. 1, p. 63) the burnout velocity would be 2×10^{5} ft/sec (135,000 mph). The time spent in acceleration would be 5×10^{7} sec (1.5 years). During this time the rocket would cover about a billion miles.

* * *

This article was based in large part on Chapter 9 of the book by R. W. Bussard and R. D. DeLauer (8).



Russians Try Plasma Bunches

Soviet researchers have recently reported* the acceleration of plasma bunches to velocities of the order of 3×10^{8} cm/sec (10^{6} fps). The plasma is formed (see figure) by discharging a condenser bank through a piece of fine wire (*aa*) causing it to vaporize into a gas-discharge plasma. Additional current flow gives rise to an electromagnetic force that accelerates the wire-shaped plasma along the parallel copper conductors. The space in which the plasma moves is evacuated to 1–2 $\times 10^{-6}$ mm Hg. The same plasma bunches, if ejected at these velocities from an outer-space vehicle, would give specific impulses ten times greater than that of present-day rockets.

* L. A. Artsimovich *et al*, Electrodynamic acceleration of plasma bunches, *Soviet Physics* (*JETP*) **6**, No. 1, 1 (1958).

* Alternative thermoelectric conversion schemes (NU, Feb. '58, p. 25, June, p. 27) may ultimately give much superior weight-to-power ratios.

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7. R. H. Boden. The ion rocket engine, SAE National Aeronautic Meeting preprint #41D (New York, 1958)
8. R. W. Bussard, R. D. DeLauer, "Nuclear Rocket Propulsion" (McGraw-Hill Book Co., New York, 1958)

Steam power units have been getting bigger . . .

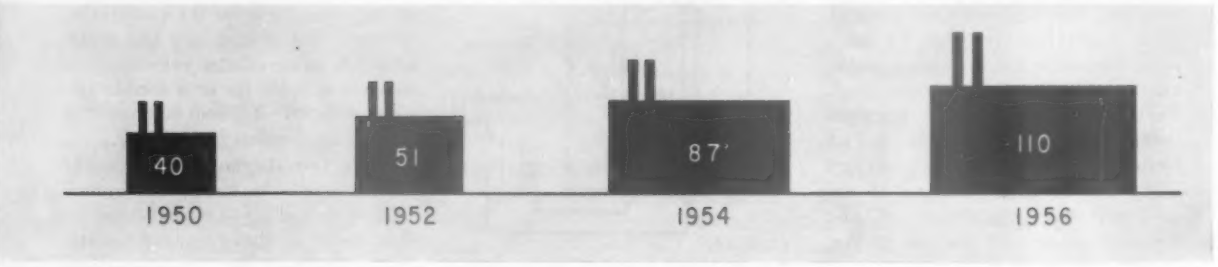


FIG. 1. AVERAGE CAPACITY OF UNITS INSTALLED, 1950–56, IN MW(e)

Trends in Power Generation—

Small steam plants can't make 7-mill power and the utilities know it. Bigger plants make cheaper power, so average plant size has tripled since '40, will quadruple by '61. The cash reasons are a lesson for nuclear power

By H. E. ROBERTS, *Bureau of Power, Federal Power Commission, Washington, D. C.*

ELECTRIC UTILITIES—both public and private—are building bigger and bigger steam plants. Plant size has tripled since 1938, and with good reason: When it comes to power production, big plants are more economical than small ones. Not only can the big plant operate at higher efficiency than small ones, but initial capital investment per kwh and operating expenses per kwh are lower, too.

Regionally, plant size varies. In general, plants are largest near the East and West coast, are smaller in the interior. Regional influences also affect fuel selection, because gas, oil and coal vary in price from place to place. In the Northwest, hydroelectric power is predominant.

Such utility trends result from long experience in the business of making and marketing kilowatts. The reasons should be studied by those who will design tomorrow's nuclear plants, too, since the basic economics of plant size, regional factors and cost breakdown will apply to nuclear power stations.

Plant Size

The increase in plant size is reflected by FPC statistics for the steam-electric power industry, which produces 79% of the national annual kwh output. Since 1940, the utilities' steam-power-plant capacity has more than tripled, while the total number of plants increased less than 15%. In 1940, for example, average plant size (nameplate capacity) was 30 Mw(e); now it's 91 Mw(e), and by 1961, it will exceed 125 Mw(e). By 1961, 67 giant plants, each with a capacity of 200 Mw(e) or more, will be in operation. On the average, these big plants will be able to produce power for about 6 mills per kwh, roughly 50% cheaper than a small 40-Mw(e) plant.

Fig. 1 shows the trend to bigger plants. On the left, units installed, 1950–56; on the right, units under construction or firmly planned for 1958–61.

Regional Trends

Average power plant size varies from region to region. Figure 2 shows the regional distribution of newer units—those built since '38—and their average capacity in megawatts. In the last 19 years, the largest units have been east of the Mississippi; the trend will continue in the next few years, with a few large units being added to the West Coast.

It might be mentioned that Region VII, the Pacific Northwest, depends mainly on hydroelectric power, so the amount of *steam* capacity there is quite limited. The whole region has but one steam system, which operates in Utah. Conversely, hydroelectric power is of much less importance in the other parts of the country.

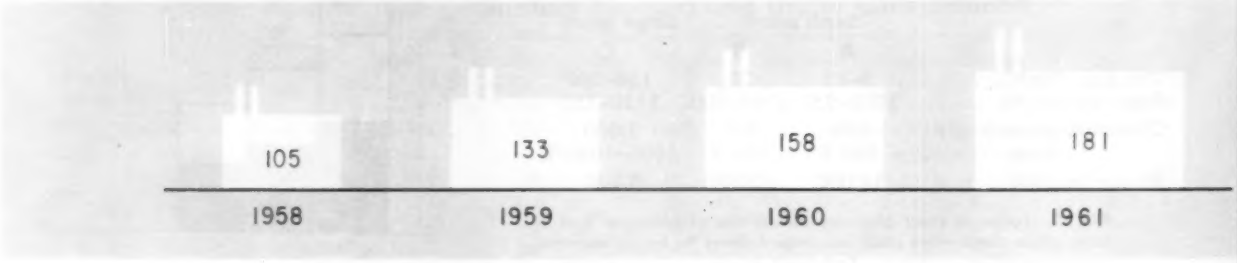
In the 19-year period, 1938–56, there were 281 new steam plants placed in service. The figures cover 64,141 Mw in 1,108 generating units, which represent about 95% of the total megawatts and over 80% of the total units installed during the period.

Table 1 shows, on the same regional basis, the steam capacity completed, under construction and definitely planned for the 5-year period, 1957–1961. The table includes both added capacity in existing plants and the capacity going into some 85 new plants.

The actual yearly additions, when reported, will vary somewhat from the predictions for any given year, since actual service dates are advanced or delayed for many reasons. Also, there have been some additions to the proposed 1961 capacity since the table was completed.

The 1957 plants listed in Table 1 are

. . . and in the future, they'll get still bigger



UNIT CAPACITY PLANNED, 1958-61, IN MW(e)

Lessons for Nuclear Engineers

already in service. Their capacity may differ from the predicted value because more and more plants now report their capacity on a capability basis instead of the conventional nameplate basis. This usually produces slightly larger totals.

Fuel Costs

Fuel costs usually account for 60–80% of the annual production expenses of steam power and 30–50% of the total cost (including annual fixed charges on plant investment). Table 2 shows the approximate amount of coal required to produce one kwh, assuming average operating conditions in modern base-load plants. The figures for the largest unit, a critical-pressure unit, are based on design data only, since only one critical-pressure unit is now in service.

In general, fuel requirements per kwh have dropped since 1940. The industry-wide average fuel consumption (oil and gas are converted to their coal equivalents) for *all* plants, old and new, is as follows:

Year	*Pounds of coal per kwh*
1940	1.34
1946	1.29
1950	1.19
1956	0.94

The decrease in coal requirements per kwh, and the relatively steady coal price—*Electrical World*, a McGraw-Hill publication, estimates roughly a

Plant size and cost vary from region to region

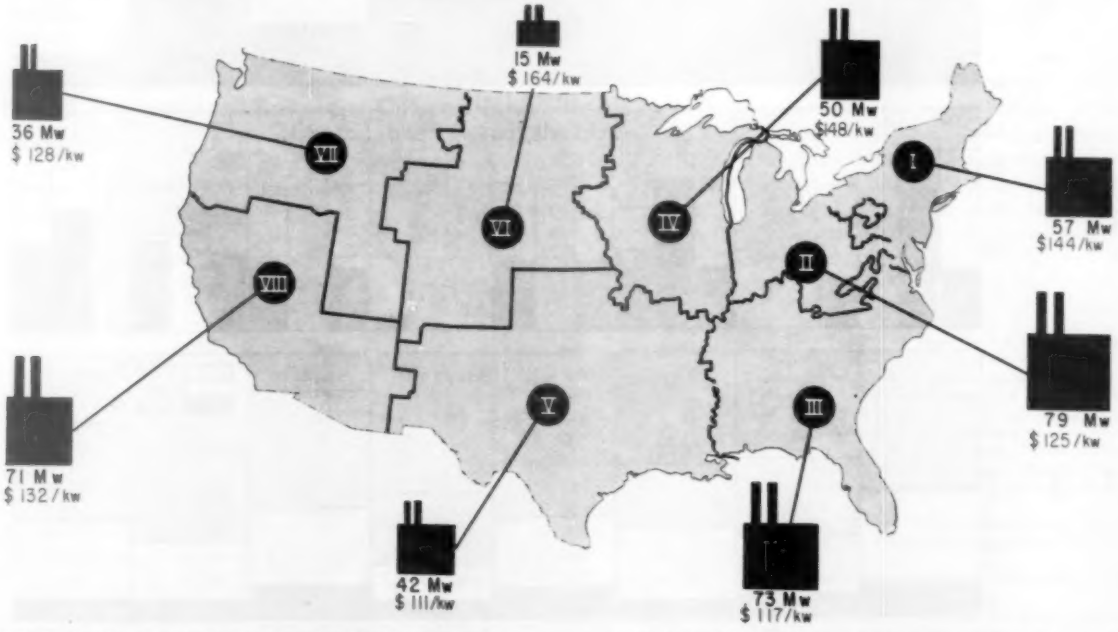


FIG. 2. Regional variation in size of turbogenerator units installed, 1938–56. Bold-face figures are average unit capacity in each of the FPC's eight power-supply areas; figures beneath indicate investor-owned plant cost per kw nameplate capacity

Power cost varies from plant to plant

	Small plant		Large plant
	A	B	C
Unit size (Mw)	5–15	33	150–200
Plant cost per kw	$200–250	$160–200	$130–150
Operating pressure (psi)	600	850	2,000
" temp.	825°F	900°F	1000–1050°F
Btu per net kwh	14,000	12,300	9,200

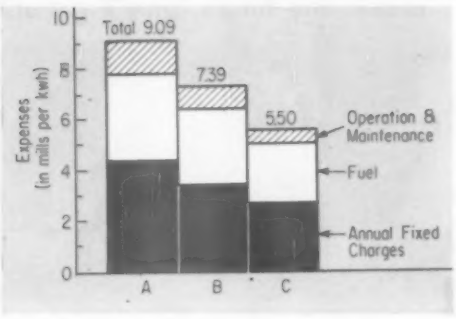


FIG. 3. Large vs small plant—a comparison of costs per kwh in three steam plants—two small, one large—shows the heavy economic advantage of larger plants. Each plant assumed to have 4 units

20% cost increase by 1975, compared with 100% for gas, 40% for oil—make coal a rough competitor in the power field for years to come.

Total Cost

Total cost of steam-electric power produced in three hypothetical plants is presented in Fig. 3. The figure shows the economies associated with the size and higher thermal efficiencies of larger, high-temperature installations. The costs given assume other conditions (plant factor, fuel cost, etc.) are equal and thus determine the effect of generating-unit size on total cost per net kwh produced.

An 80% annual plant factor has been assumed, but 60% seems more realistic over a long period. At a 60% factor, the total costs per kwh for plants *A*, *B* and *C* would be 11 mills, 9 mills and 6.6 mills, respectively—increasing the competitive edge of larger plants.

Figure 4 summarizes total costs by regions for 57 privately-owned systems and pools based on 1956 operation.

Fuel prices, plant factors, and total cost by regions

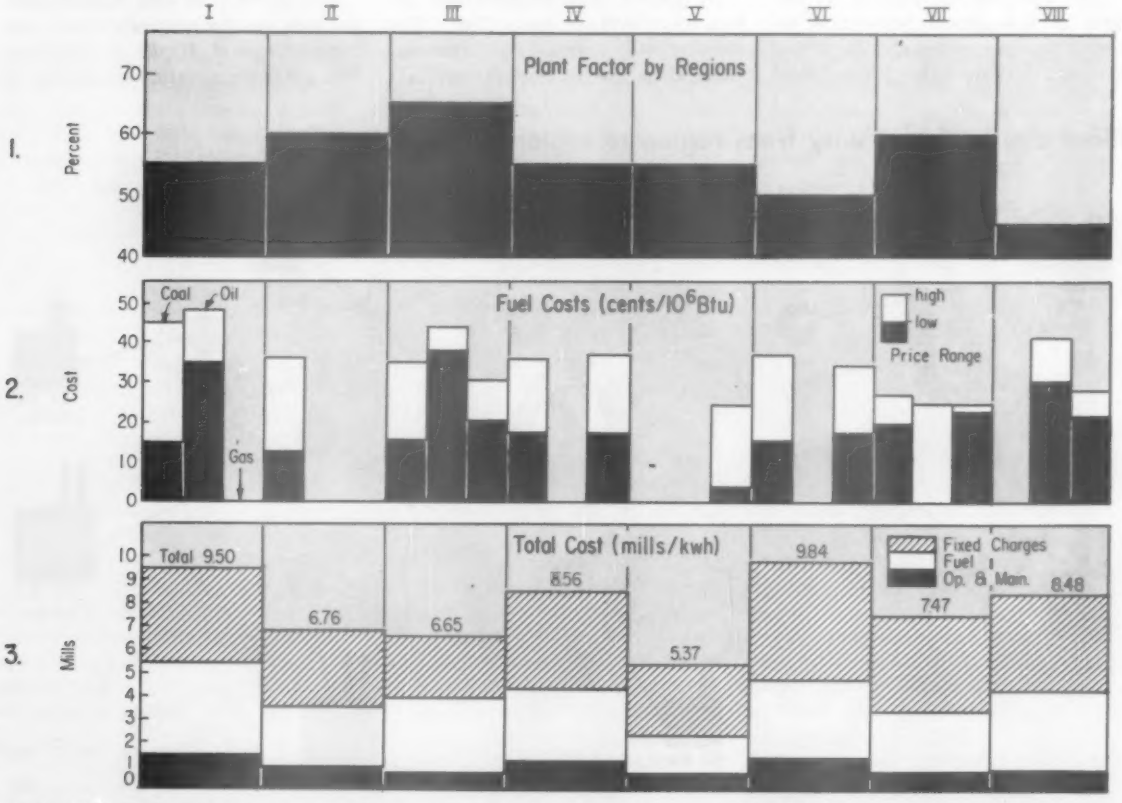


FIG. 4. Total cost by regions of steam-electric power in 57 privately-owned systems (1956). Costs are broken down to show influence of 1) plant factor, 2) fuel cost, and 3) production expenses in each of the 8 regions shown in Fig. 2

TABLE 1—Steam-Electric Turbogenerators Planned and Under Construction*

Turbogenerator capacity (Mw)	Region I		Region II		Region III		Region IV		Region V		Region VI		Region VII		Region VIII		Total U. S.	
	Units	Mw	Units	Mw	Units	Mw	Units	Mw	Units	Mw	Units	Mw	Units	Mw	Units	Mw	Units	Mw
≥12.65	2	25	12	100	2	25	14	120	10	87	2	15	1	13	—	—	43	385
16.5–44	8	200	8	198	6	140	24	704	18	470	11	275	—	—	6	264	81	2,251
50–66	—	—	2	132	—	—	1	50	2	100	1	50	—	—	5	330	11	662
75	6	450	—	—	8	600	5	375	4	300	—	—	—	—	4	300	27	2,025
100	7	700	4	400	2	200	5	500	17	1,700	7	700	1	100	4	400	47	4,700
125	9	1,125	12	1,500	16	2,000	2	250	1	125	—	—	—	—	1	125	41	5,125
156/165	6	953	19	3,100	11	1,725	4	624	14	2,300	—	—	—	—	5	825	59	9,527
200	4	800	2	400	2	400	3	600	10	2,000	—	—	—	—	5	1,000	26	5,200
225	2	450	—	—	3	675	—	—	—	—	—	—	—	—	—	—	5	1,125
250/275	2	550	4	1,000	8	2,125	3	775	—	—	—	—	—	—	—	—	17	4,450
300/33	4	1,300	5	1,675	—	—	5	1,625	—	—	—	—	—	—	2	670	16	5,270
450	—	—	2	900	—	—	—	—	—	—	—	—	—	—	—	—	2	900
500	—	—	—	—	1	500	—	—	—	—	—	—	—	—	—	—	1	500
Totals	50	6,553	70	9,405	59	8,390	66	5,623	76	7,082	21	1,040	2	113	32	3,914	376	42,120
Average Unit Size (Mw)	131		134		142		85		93		50		56		122		112	

* Planned for service in 1957–1961 by total electric power industry as of Sept. 1957.

The 57 systems with 73,528-Mw(e) capacity and 365 billion kwh accounted for 92% of the steam capacity and 90% of the steam power production of the privately-owned electric utilities in 1956.

This total-cost summary covers all actual reported costs except annual fixed charges—return on investment, depreciation, and taxes—which have been estimated on a reasonable national average of 13½%. (Of course, the 13½% average is not necessarily applicable to any one particular system.) In addition, Fig. 4 does not cover administrative and general expense, an overhead item that usually adds another 0.2–0.3 mills per kwh.

Cost Trends

The costs discussed here cover all of the steam capacity in the reported systems—the newer, more efficient plants as well as the older, less efficient ones. Despite increased construction, operating, maintenance and fuel costs over the past decade, many of the older systems actually have lower total costs per kwh produced today than they did ten years ago. The main reasons are technical advances in steam power generation and high-plant-factor operation of the most efficient capacity in the system. In other words, the newer, more efficient units run almost constantly; older, less efficient units are used only to cover peak loads. This operating procedure would presumably justify the nuclear engineer's assumption of high plant factors to compute potential power costs with nuclear equipment.

TABLE 2—Net Heat Rates for Conventional Plants

Turbogenerator size (Mw)	Operating steam conditions: Pressure (psig)	Temperature (VF)	Reheat?	Btu per net kwh	Lb coal (or equivalent) per net kwh*
5	600	825°	(Non-reheat)	15,500	1.28
8	"	"	"	15,200	1.26
13	"	"	"	13,250	1.10
22	850	900°	"	12,500	1.03
33	"	900°	"	12,200	1.01
44	1,250	950°	"	11,500	0.95
50	1,450	1,000°	1,000° reheat	10,300	0.85
75	"	"	" "	10,000	0.83
100	"	"	" "	9,700	0.80
125	1,800	"	" "	9,500	0.79
150	"	1,050°	" "	9,300	0.77
200/250	2,000	"	" "	9,200	0.76
300/335	2,400	"	1,050° "	9,000	0.74
450	3,500	"	1,050° double reheat	8,500	0.70

* At 12,100 Btu/lb of coal.

* * *

The Federal Power Commission, as a matter of policy, disclaims responsibility for any private publication by any of its employees. The views expressed herein are those of the author and do not necessarily reflect the views of the Commission.

The information contained in the tables and charts in this article was obtained from the Federal Power Commission sources listed below:

Steam-Electric Plant Construction Costs and Annual Production Expenses—1938 to 1956.

Monthly Electric Power Statistics—1938 to 1956.

Statistics of Electric Utilities in the United States, Privately-owned—1938 to 1956.

Statistics of Electric Utilities in the United States, Public-owned—1950 to 1956.

Gamma-Ray Attenuation with Buildup in Water

By DAVID G. CHAPPELL, *Knolls Atomic Power Laboratory, General Electric Co., Schenectady, New York*

This nomogram gives the attenuation factor for a water shielding slab used with a point source of gamma radiation. Two predecessors that do the task for iron and lead have already been presented in NUCLEONICS Data Sheet No. 18 ("Gamma Attenuation with Buildup in Lead and Iron"—NU, Jan. '57, p. 52).

Like its predecessors this nomogram includes the effect of buildup—the scattering of degraded radiation into the beam from all points of the slab. Absorption coefficients and buildup factors are taken from the report APEX 176.*

Attenuation factor $\pi_{pt} = B(\mu x)e^{-\mu x}$, where B is the buildup factor for this geometry, μ is the linear absorption coefficient, and x is the shield thickness. It does not include any allowance for source-to-detector distance. Water density is taken as being equal to 1 gm/cm³.

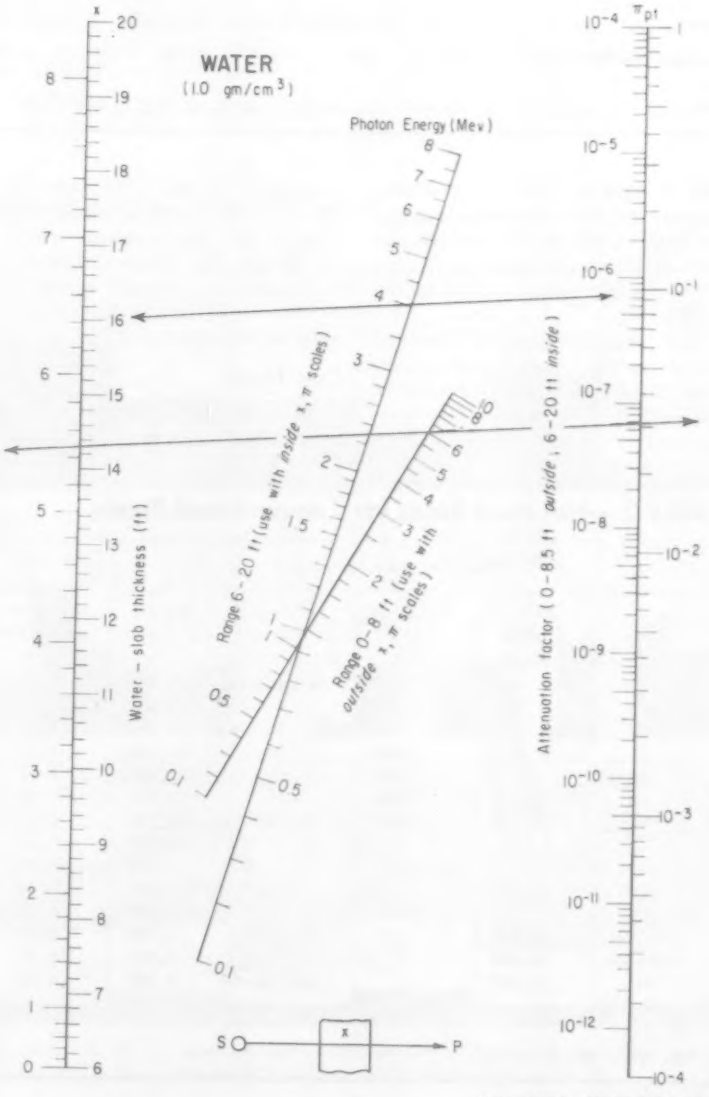
Examples. (1) By how much will 4-Mev gamma rays from a point source be attenuated in passing through a 16-ft layer of water? The upper of the two sample lines shows that the answer is 7.5×10^{-7}.

(2) We wish to attenuate 6-Mev photons by a factor of 3.1×10^{-2}. How thick must a water slab be to do it? The lower of the two sample lines yields the answer: 5.5 ft.

* * *

I wish to acknowledge the assistance of Miss Janice L. Noble, who drew the nomogram.

* Miscellaneous data for shielding calculations. Compiled by John Moteff. APEX 176 (1954).


WATER
(1.0 gm/cm³)
Photon Energy (Mev)
Water – slab thickness (ft)
Range 6 - 20 ft (use with inside x, π scales)
Range 0 - 8 ft (use with outside x, π scales)
Attenuation factor (0 - 8.5 ft outside, 6 - 20 ft inside)
S
x
P

Measuring Reactor Spectra with Thresholds and Resonances

Fission probes and activation detectors have been used to measure and compare neutron spectra in four reactors. Better cross section data will permit refining the method

By J. B. TRICE*
Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

NEUTRON SPECTRA in reactors can be measured by making use of resonance and threshold reactions. The miniature fission probe described on page 84 has been employed along with activation detectors to measure spectra in four reactors: the Bulk Shielding Reactor (BSR), the Low Intensity Test Reactor (LITR) and the Graphite Reactor (X-10) at the Oak Ridge National Laboratory and the Materials Testing Reactor (MTR) at the National Reactor Testing Station in Idaho. The method is sensitive to cross-section data, and as these data improve, it can undoubtedly become an incisive approach to knowledge of reactor neutron spectra.

Methods

Nuclear reactions used as a basis for spectral analyses fall into three categories: fission, neutron-induced charged-particle emission and resonance. These three groups of reactions, with their applicable threshold and resonance energies are exhibited in the table on this page.

Fast flux. Fission measurements were made with Np^{237}, U^{238}, and Th^{232} in the miniature fission chambers described later on page 84. These materials are activated almost uniformly by neutrons with energies between their effective thresholds and ~5 Mev.

Neutron-induced charged-particle emissions occur in several materials with threshold energies scattered over a wide interval. In general their cross sections are not known as precisely as fission cross sections. However, these reactions provide valuable information regarding high-energy regions that can not be measured with fission reactions.

Effective threshold energy is defined in terms of the idealized step-function cross section (*1*). It is that energy at which the step should be placed so that the actual number of reactions corresponds to the number computed from the idealized cross section. Fission-threshold materials obey this kind of an approximation quite well. So do certain neutron-particle reactions, and they offer the advantage of several materials that are appropriate for reactor measurements such as sulfur and phosphorus.

Many other reactions, however, subject to large uncertainties in their cross sections, resemble the threshold model poorly or not at all. Examples are the neutron-charged-particle reactions in aluminum and magnesium. The cross sections for these reactions have been measured in integral form using fission neutrons, and their effective thresholds are calculated from theoretical considerations (*1*). Nevertheless, these reactions have been used with considerable success.

Reactions Used to Measure Flux

Energy (kev)	*Reaction*
Resonance reactions	
0.260	$Mn^{55}(n,\gamma)Mn^{56}$
0.562	$Cu^{63}(n,\gamma)Cu^{64}$
1.71	$Na^{23}(n,\gamma)Na^{24}$
1.80	$Cl^{37}(n,\gamma)Cl^{38}$
3.00	$V^{51}(n,\gamma)V^{52}$
9.10	$Al^{27}(n,\gamma)Al^{28}$
Threshold reactions	
600	Np^{237}(fission)
~600	$Cl^{35}(n,\alpha)P^{32}$
1,300	U^{238}(fission)
2,000	Th^{232}(fission)
2,400	$P^{31}(n,p)Si^{31}$
2,900	$S^{32}(n,p)P^{32}$
4,600	$Al^{27}(n,p)Mg^{27}$
5,500	$Si^{28}(n,p)Al^{28}$
6,300	$Mg^{24}(n,p)Na^{24}$
8,100	$Al^{27}(n,\alpha)Na^{24}$

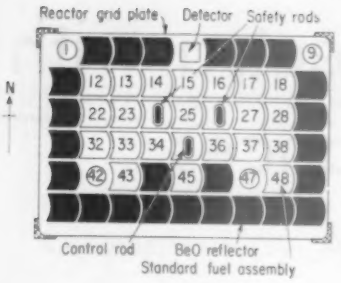
Epithermal flux. Determination of the epithermal spectrum depends on determinations of cadmium ratios. These are measured as functions of position for the resonance detectors in each experiment and compared with a corresponding set of "standard" cadmium ratios. The standard ratios were measured in a carefully selected graphite moderator having a $1/E$ epithermal spectrum. Such standard spectral characteristics were determined in 1946 (*2*). They extend from a few electron volts to >9 kev and rely on the absorption resonances of the activated materials used.

We follow the method of Dancoff, in which a neutron spectral function ϕ_0/E is written in terms of the cadmium ratio R, thermal flux ϕ_{th}, a number characteristic of the resonance α, a normalization constant for the $1/v$ part of the cross section σ_0, the thermal activation cross section for a Maxwellian thermal neutron flux σ_{th}, and the energy of the cadmium cutoff E_{Cd}. In units of n/cm²/sec/Mev this function is

$$\frac{\phi_0}{E} = \frac{\phi_{th}(E_{Cd})^{\frac{1}{2}}\sigma_{th}}{2\sigma_0(1+\alpha)(R-1)E}$$

An equivalent form developed by

* PRESENT ADDRESS: Aircraft Nuclear Propulsion Dept., General Electric Co., Evendale, Ohio.



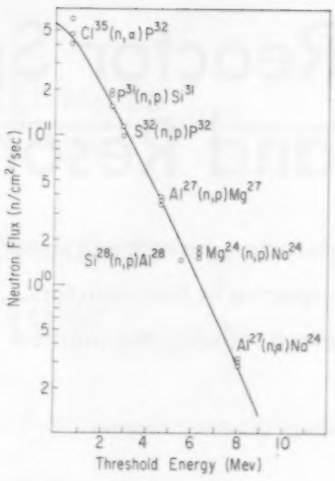
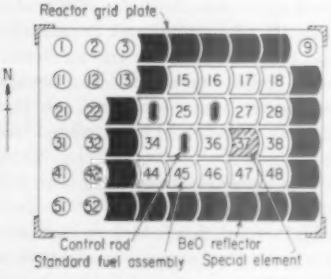


FIG. 1. A BSR configuration and flux observed at indicated position in reflector. Total flux above each threshold is plotted against effective threshold energy. Curve is integral fission spectrum normalized to $Al^{27}(n,p)Mg^{27}$ points



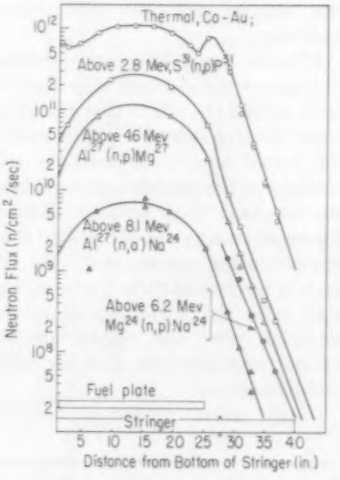
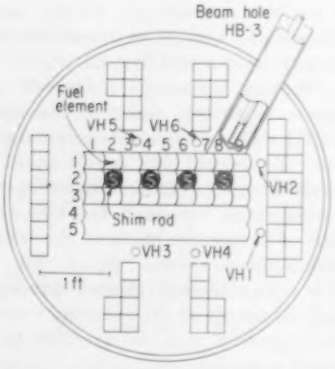


FIG. 2. Another BSR configuration and resulting flux profiles plotted by inserting several threshold detectors different distances into special fuel element at position 37. Ordinates are total fluxes above threshold. Power was 100 kw



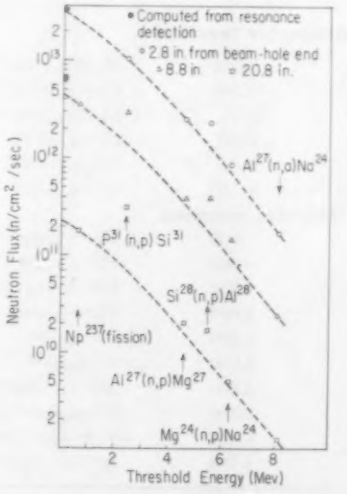


FIG. 3. MTR configuration and flux measured at various positions in beam hole HB-3. Dotted lines are fission spectrum for comparison. Ordinates have same meanings as in Figs. 1 and 2

Muehlhause and others (*3*) uses the following equations

$$\phi_0 = \phi_{th}/K$$

$$\Sigma_{a'} = \frac{K\sigma_{th}}{R-1} = \int_{E_{Cd}}^{\infty} \frac{\sigma(E)dE}{E}$$

To determine whether or not the epithermal flux is proportional to $1/E$, one determines ϕ_0 with several different resonance detectors. If the values of ϕ_0 are not equal, the data can not be used. In general, however, a fair agreement has been observed among the values of ϕ_0 indicating the existence of $1/E$ dependence. Spectra obtained in this manner are expressed here as plots of the function ϕ_0/E versus the resonance energy E at which a characteristic absorption is thought to occur.

Flux Measurements

Figures 1–6 show the high-energy fluxes observed at BSR LITR, X-10, and MTR.

BSR. Figures 1 and 2 display BSR spectra. Cross plots of the curves in the second set of measurements reveal close adherence to the fission spectrum near the center of the lattice. At a distance of a few inches above the lattice and in the water, the fission form no longer fits. Lower-energy neutrons build up with moderation and distort the fission profile.

MTR flux profiles were measured in beam hole HB-3. The results in Fig. 3 contain data derived from five threshold reactions, one series of measurements with Np^{237}-loaded fission chambers and two points derived from analysis of resonance-detector measurements. Fission chambers yielded the most interesting data.

Figure 4 shows a comparison of two profiles taken with Np^{237} and Th^{232}. It indicates that the neutron groups monitored by the two thresholds do not differ significantly. The profile obtained with U^{238} was identical to the Np^{237} profile, further evidence that the neutron spectrum was flat along the beam-hole traverse.

Figure 3 shows how well the Np^{237}-measured flux fits on a fission-spectrum plot at two positions along HB-3. The Np^{237} probes were the only ones in which the weights of the plated materials were known accurately. This is partly a result of the characteristics of Np^{237}; it has copious alpha particles that are easily counted. Weights that

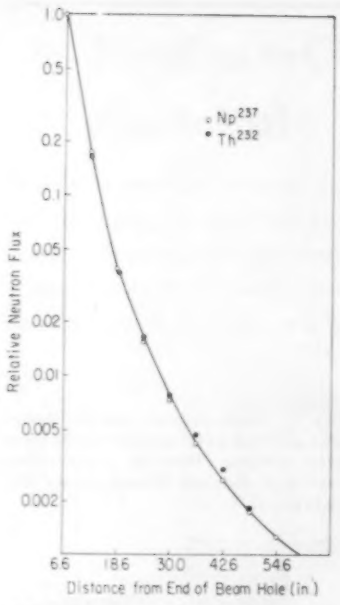


FIG. 4. Comparison of neutron fluxes above thresholds of Np^{237} and Th^{232} in HB-3 of MTR. Fluxes are arbitrarily normalized to unity at measurement position nearest lattice

were used for Th^{232} and U^{238} were found to be faulty because of faulty calibration measurements. Therefore the neutron flux above 0.6 Mev was measured with Np^{237} and recorded with the measurements from other detectors.

At a distance slightly less than 4 in. from the lattice, the ionization from gamma rays swamped the chamber, thus prohibiting the measurements at the 2.8-in. position of Fig. 3.

LITR. Neutron spectra in the HB-2 beam hole of LITR are displayed in Fig. 5. These were extracted from integral flux data of the type described previously. They show how the neutron spectrum changes as the neutrons stream away from fissioning uranium fuel and are moderated.

The curves are not highly resolved. However, they do reflect broad spectral changes as measured with resonance detectors and threshold detectors. It is apparent that the hump in the curve measured close to the lattice disappears with increasing distance. Neutrons disappear from the fission profile and reappear at lower energies in the spectral tail.

Comparison of Spectra

There is a remarkable difference between thermal-to-fast flux ratios we observe in MTR and LITR. In MTR at the position nearest the lattice, thermal flux is eight times fast flux. In LITR on the other hand fast flux is equal to thermal flux. The two lattices are essentially alike, and LITR was originally a mockup for MTR. Thus the measurements emphasize the rate at which the fast-to-thermal ratio falls off toward the lattice corner, a result of more reflector and less fuel. As indicated in the figures the LITR measurements were in a center beam hole, whereas the MTR measurements were made at a corner.

Another interesting comparison can be made between spectra in two basically different reactors—X-10 and BSR. The epithermal spectra, which result from fuel-moderator composition and proportion, reveal themselves through comparisons between the epithermal-to-thermal-flux ratios in BSR and a doughnut hole (1867) in X-10. This analysis is facilitated by resonance-detector data such as the group of measurements shown in Fig. 6 for BSR. The epithermal energy interval 0.1–10^4 ev was selected as a convenient range. The ratio of epithermal flux to thermal flux is slightly more than ½ for the doughnut hole in X-10 and only $\frac{1}{10}$ for BSR. The higher relative epithermal flux in the graphite reactor probably results from higher fuel concentration in the doughnut hole.

It can be seen that the proportion of fast or epithermal neutron flux in the flux spectrum in and around any reactor depends strongly on position. Used with care, threshold and resonance detector data provide sufficient spectral information to enable experiments that require knowledge of the neutron spectra.

* * *

The generous and enthusiastic support of many persons is responsible for the work reported herein. From the Oak Ridge National Laboratory, T. L. Trent designed the pneumatic machinery for MTR experiments; F. J. Muckenthaler and H. V. Klaus performed many of the measurements both at Oak Ridge and Idaho. P. M. Uthe, USAF, calibrated and operated the fission chambers which were designed by R. E. Zedler at ORNL. P. M. Uthe was responsible for the success of the hundreds of foil and chamber measurements performed at the MTR in the summer of 1954. R. H. Lewis, now at Babcock and Wilcox, assisted the project by supervising the counting and analysis of foil data. J. F. Moteff, General Electric ANP, and J. F. Krause, Pratt and Whitney Aircraft Corp., analyzed much of the data and assisted in the operation of the MTR experimental facilities. For many helpful suggestions and encouraging support, thanks are due D. S. Billington and members of the Solid State Division, Oak Ridge National Laboratory.

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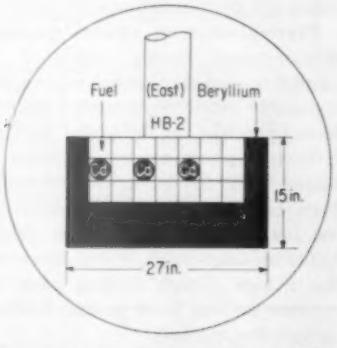
3. C. O. Muehlhause, S. P. Harris, G. E. Thomas, *Phys. Rev.* **79**, 12 (1950)



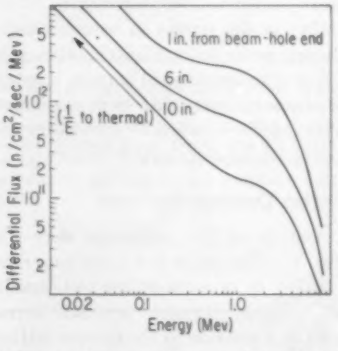


FIG. 5. LITR configuration and differential flux at three positions in beam hole HB-2. Power was 1 Mw. Spectrum shifts with changing distance

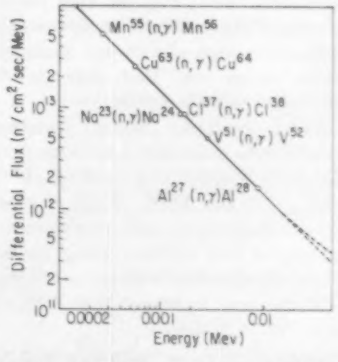


FIG. 6. BSR epithermal flux. Configuration of Fig. 1; power, 100 kw

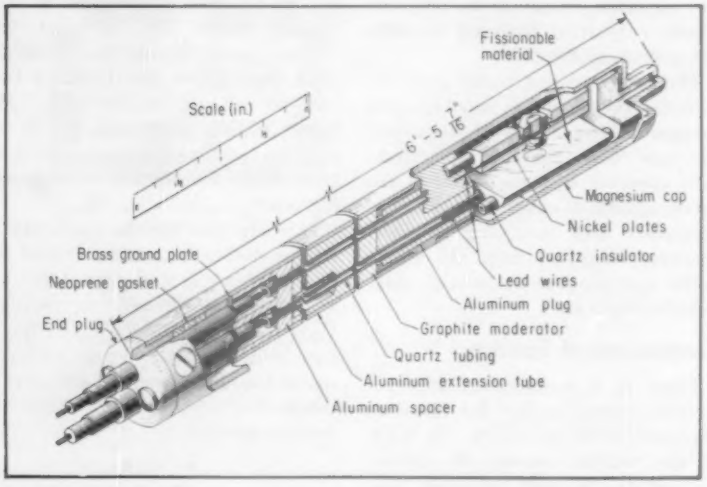


FIG. 1. Fission chamber has interchangeable electrodes that are plated with fissionable isotopes. Flow of argon-methane mixture is sustained through hollow high-voltage cable

Miniature Fission Chamber

By J. B. TRICE*
Solid State Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

To exploit nuclear threshold reactions for neutron-spectrum measurements, miniature fission chambers have been designed and built for use in high-intensity radiation fields. Some measurements made with these chambers and with activation analysis are described on pages 81–83.

Such measurements are difficult for several reasons. Inside a reactor, space for experimental apparatus is limited, particularly in high-flux reactors that are required for radiation-damage experiments. Such space restrictions prohibit two of the most widely accepted devices for measuring neutron spectra: proton-recoil spectrometers and nuclear emulsions. Moreover gamma fluxes are sufficiently intense to cloud almost any measurement except one that depends on activation or fission pulses.

These miniature fission chambers measure the ionization pulse rate from fissioning of one of four nuclides—U^{235}, Np^{237}, U^{238} and Th^{232}. Each of these is used singly in the chamber to measure one of four neutron energy bands. Their effective thresholds are as follows: U^{235}, thermal; Np^{237}, 0.6 Mev; U^{238} 1.3 Mev; Th^{232}, 2 Mev.

Advantages

The important advantages of the fission probes over other methods are (a) their accessibility to high-flux regions through very small access holes, (b) their ability to supply information immediately, (c) the close resemblance between the energy dependence of their cross sections and that of an ideal threshold detector, and (d) the existence of accurate, high-resolution cross-section data for all of the fissionable materials used in the probes.

In contrast, activation analysis requires counting measurements and decay-curve plotting, and it affords more opportunities for errors. The ability of the probes to measure high-energy neutrons with acceptable precision was established during a series of measurements that were compared with results obtained by activation and nonfissioning threshold detectors.

Probe Description

Details of the probe are shown in Fig. 1. The probe is a 15-ft long rigid cylinder ¾ in. in diameter and capable of insertion through a small access hole to a position in the reactor lattice. The probe can reach more than 15 ft into the reactor from the face.

Remote operation of the chamber is possible through an optimum choice of electrical characteristics of the conductors leading to it. The capacitance of the leads to the chamber has been minimized so that a long cable can be used to connect the fission-chamber outlet to the preamplifier.

The small ionization chamber in which fission occurs is at the tip of the probe. A constant flow of 97% argon and 3% methane is supplied to the chamber through a hollow high-voltage cable and down the probe center. It exhausts into the beam hole through a small opening in the tip of the chamber. The cylindrical housing that covers the electrode plates in the tip is detachable so that plates can be removed and replaced.

Thermal-neutron shielding. For measurements during which it is desired to exclude thermal neutrons—a possible source of unwanted fissions from impurities on the plates such as U^{235}—a cadmium-magnesium cover is placed over the chamber electrodes. Pure cadmium is avoided because of its low melting point. The 50-50 cadmium-magnesium alloy, however, has a high enough melting point to prevent melting from gamma heating in high-flux reactors.

Standard preamplifiers and amplifiers are used with scalers and recorders to count and record fissions. A

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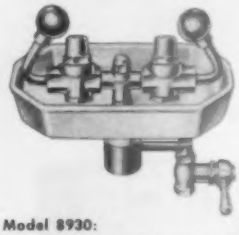

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This article starts on page 84

counting-rate meter permits observation of fission rates.

Electrodes. Nickel is superior to aluminum as a surface to which the fissionable materials adhere. Electroplating is most successful in plating the electrodes.

Requirements

The major developmental problems involved the needs for (a) minimized capacitance of the 15-ft probe lead so that a useable pulse-height plateau could be obtained, (b) a construction that would sustain high performance characteristics for operation times up to 200 hr in fluxes of $>10^{10}$ fast neutrons/cm²/sec with correspondingly high intensity gamma fields, and (c) an accurate determination of the probe-counter efficiency for each of the fissionable materials.

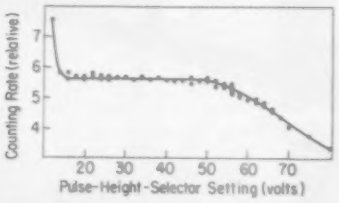


FIG. 2. Good plateau in pulse-height-against-counting-rate curve is obtained if lead capacitance is small enough. Curve was made with 37,000 gain, 360-volt collecting potential, 0.5-Mc band width, U^{235} plates and a flux of 1.42×10^6 n/cm²/sec

Lead capacitance. The lead-capacitance problem was solved by varying both geometry and materials of the signal-lead system. A minimum distance of 16 ft between the chamber and its preamplifier resulted in a lead capacitance of 430 $\mu\mu$f—so large that the signal from the probe was severely attenuated and distorted by the time it reached the preamplifier. As a result there was no plateau in the curve of counting-rate as a function of pulse height. The capacitance was subsequently reduced to 180 $\mu\mu$f for 21 ft by using 10-mil nickel wire instead of 25-mil copper wire as the center conductor for the signal lead and increasing the inside diameter of the fused-quartz insulators in the probe. Figure 2 shows a typical pulse-height plateau.

Radiation stability. Operation of the probe for 50 hr in a field of 10^{11} fast neutrons/cm²/sec together with

the accompanying gamma field of $\sim 10^{12}$ gammas/cm²/sec indicates good radiation stability. Breakdown did occur at intensities of $\sim 10^{12}$ fast neutrons/cm²/sec, but it was probably caused by the accompanying gamma rays and not by the neutrons.

A convenient feature of the probe is that after hours of irradiation in a neutron field of 10^{12} thermal neutrons/cm²/sec it can easily be handled after a day or so of cooling.

Calibration

The probe was calibrated in the ORNL thermal column, which provides a satisfactory plane source of thermal neutrons in water. The ratio of thermal to fast neutron fluxes in this facility is approximately 10^6. Calibration consisted of a comparison of thermal neutron flux measured with the probe using U^{235} and a gold foil mounted on the side of the probe tip.

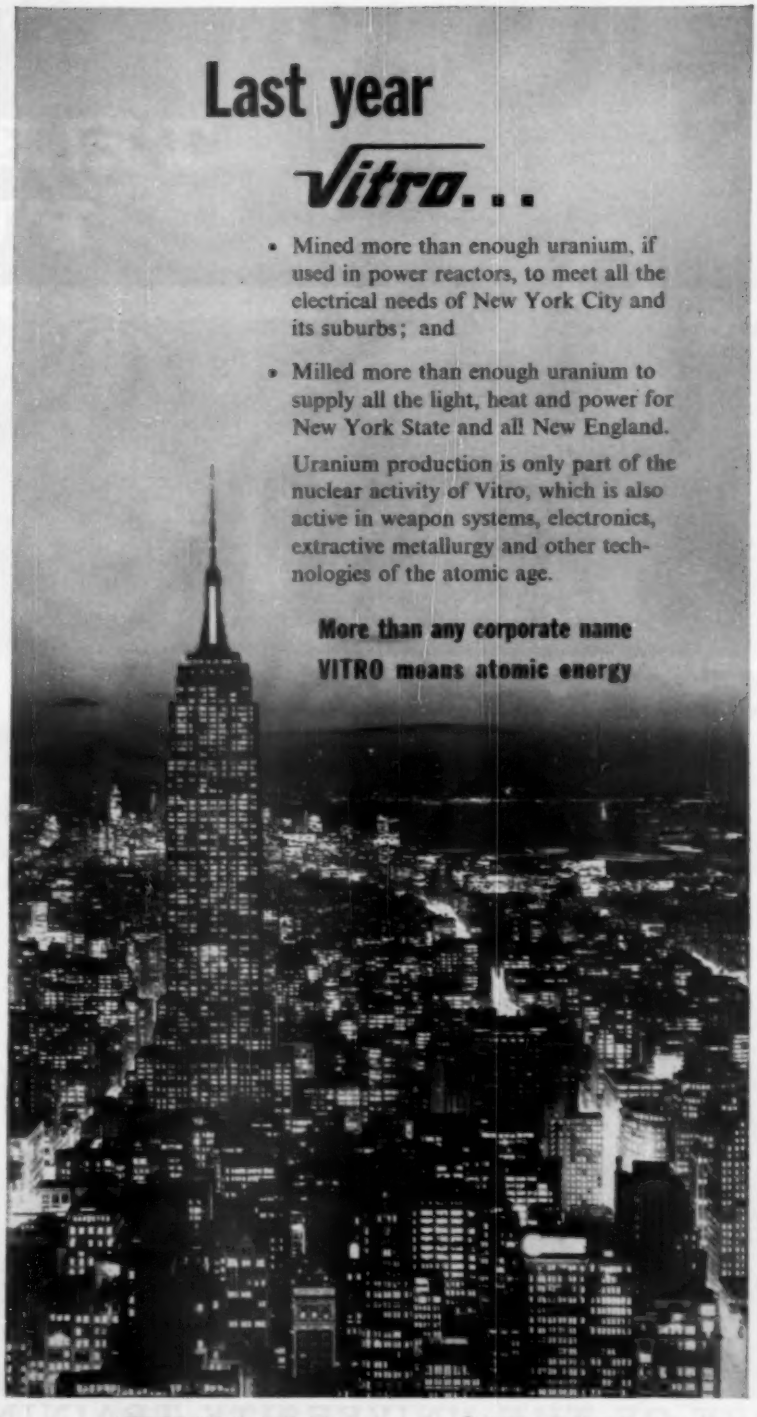
Only after comparative measurements of a foil placed on the external surface of the probe and a foil placed between the electrodes agreed within experimental error ($\pm 1\%$) was it assumed that the gold foil mounted on the side of the probe had been exposed to the same flux as the probe electrodes.*

Detection efficiency of the probe for fissions occurring in it as determined by these measurements is $98 \pm 1.8\%$. This probe efficiency was thought to be completely valid for the fissionable materials with higher energy thresholds, particularly since the calculated response agreed with the measured response to thermal neutrons. Because <100 μg of fissionable material is in the probe, local flux distortion is not a problem.

Applications

The fission probes were designed and developed to measure reactor neutron spectra at the site of radiation damage experiments. Their success in this role is discussed on pages 81–83. Another usefulness under consideration at ORNL is that of a reactor power monitor. In certain experiments it is desired that the reactor power be controlled precisely. A fast-flux neutron monitor provides a better measure of average power than a thermal monitor, which is more susceptible to variations caused by local poison buildup, flux depression and, in high fluxes, burnup of the monitor itself.

* Flux depression due to the gold foil was determined to be $< 1\%$ in a separate measurement.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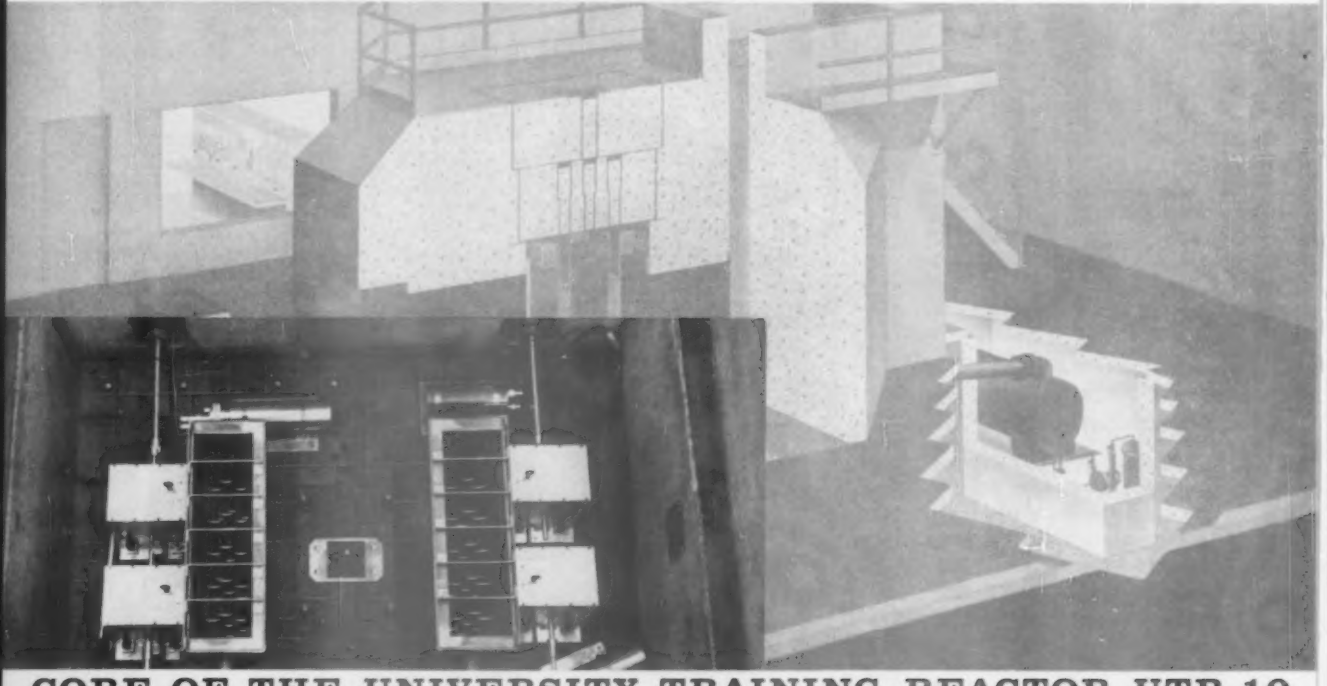

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Single-Channel Counter for Carbon-14 and Tritium

By T. S. HODGSON, B. E. GORDON and M. E. ACKERMAN*
Martinez Research Laboratories, Shell Oil Company, Martinez, California

We have designed an economical, room-temperature liquid-scintillation counter that is capable of counting carbon-14 activities of 10 cpm above background. Careful photomultiplier selection also provides adequate efficiency and stability for tritium assay.

A major factor in the rapid development of liquid-scintillation counting in recent years (*1–8*) has been the marked improvement in photomultiplier performance. Although still scarce, photomultipliers are available having the necessary efficiency and high signal-to-noise ratio.

The development of liquid-scintillation counters has proceeded along two lines, single-channel and coincidence (dual-channel) counters (*7–11*). The first type employs one photomultiplier and counts all pulses whether they arise from photons originating in the counting solution or from noise electrons originating within the photomultiplier tube. The coincidence counter, which employs two tubes, circumvents the thermal-noise component by counting only those pulses arriving simultaneously at both photomultipliers.

Single-channel counters have some advantages over coincidence counters—lower cost, greater simplicity and higher efficiency. These advantages are offset by the fact that the photomultiplier tubes must be of considerably better signal-to-noise ratio than those in coincidence counters. Such tubes are still difficult to obtain.†

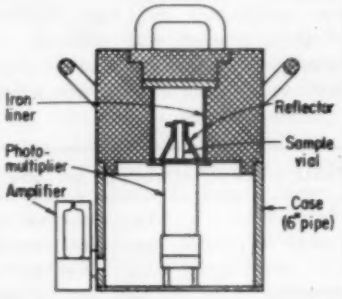

FIG. 1. Detector unit. Photomultiplier and sample are shielded in lead

Most counters reported operate at reduced temperatures. Carbon-14 assay at room temperature has been occasionally reported, but there has been no report of tritium assay at

* PRESENT ADDRESS: Chemistry Dept., University of New Mexico, Albuquerque, N. M.

† Du Mont currently offers tubes made for high efficiency and high signal-to-noise ratio as its "K" series. Our experience has shown that even with these tubes rejection may be as high as two out of three.

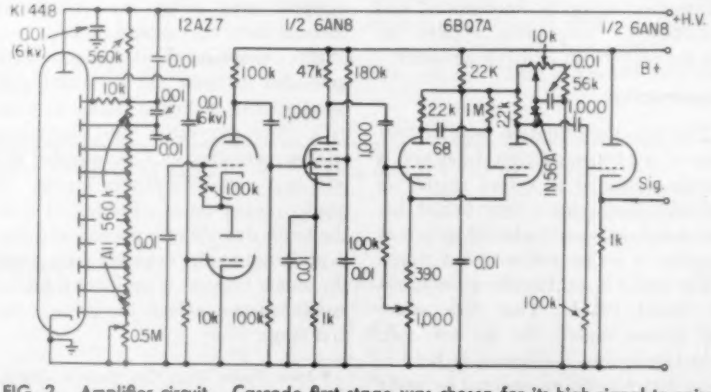

FIG. 2. Amplifier circuit. Cascode first stage was chosen for its high signal-to-noise ratio

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room temperature. This is because the thermal noise in a photomultiplier lies principally in an energy range below that of carbon-14 but overlapping that of tritium.

Our work was prompted by the success of Pringle *et al.* (*9*) in constructing a room-temperature liquid-scintillation counter for carbon-14 having a background of <7 cpm and an efficiency of ~60%. The extraordinarily low background and high stability of their counter was achieved by broad-band pulse discrimination, elaborate shielding against spurious pulses and the use of a photomultiplier tube of excellent characteristics.

Our purpose was to design a simpler, more economical and more easily assembled version of the Pringle counter. The counter described here was designed for carbon-14 and has performed satisfactorily in this service for more than one year. Because of its excellent stability, background and efficiency it has been applied to tritium assay with gratifying results.

Construction

The liquid-scintillation counter consists of a photomultiplier tube and a sample container in a lead shield, an amplifier containing a pulse-height discriminator, low- and high-voltage power supplies, a scaler and a preset timer.

The scaler is an Atomics glow-transfer model 162-A. This slow scaler was chosen mainly for its low cost. Coincidence-loss correction is bothersome, but it could be avoided by using a fast-input decade strip (at increased cost). Since the resolving time of the amplifier is of the order of 4 μsec, it is still fast enough to drive a scaler of considerably higher speed than the one used in this work, if this is desirable.

The high-voltage power supply is a John Fluke model 400 FGS.* The low-voltage power supply was constructed in this laboratory.

The detector unit (Fig. 1) is built in a 5-in. length of 6-in. pipe fitted with a bottom cover and supporting a 2-in.-thick lead shield, light-tight lid and reflector. The short length of 6-in. pipe contains the photomultiplier mounted coaxially, together with its associated high-voltage divider, filter and coupling condensers and a control to vary the voltage between photocathode and first dynode (focusing voltage).

The amplifier (Fig. 2) is built in a box mounted on the side of the detector-unit case. This location was chosen to provide the shortest path for the high-impedance, low-level signal from the photomultiplier. Noise developed here is as undesirable as thermal noise and should be kept low.

The cascode first stage, with grounded cathode and low-value grid resistor, has a higher signal-to-noise ratio than any other tried, including triodes, pentodes, cathode-coupled triodes and cathode-follower inputs. A positive input pulse, as obtained from the tenth dynode of a photomultiplier, is preferred to the negative pulse from the anode because it provides a higher signal-to-noise ratio at the plate of the first stage.

TABLE 1—Effect of Voltage on Tube Noise and Background

	Counts per minute			
	Tube noise		*Background*	
Operating voltage	*2/13/57*	*7/30/57*	*2/13/57*	*7/30/57*
800		0	26	21
900		0		31
1,000	0	2	37	36
1,050	5	6	42	43
1,100	34	26	77	68
1,120		44		88
1,150	138	83	172	135
1,160		97		150
1,180		146		207
1,200	452	208	468	255

* John Fluke Mfg. Co., Seattle, Wash. This model has recently been replaced by the model 405.

The pentode second stage is conventional. The pulse discriminator is a Schmitt trigger circuit with added diode clipper and clamp. This produces square pulses 5 volts high and 5 μsec in duration with rise and decay times of 0.2 μsec. Pulse discrimination is provided by the control between grid and cathode. The high gain obtained with only two tubes in this amplifier is not typical and results from the use of long coupling time constants. It was thought that high speed was unimportant when the amplifier was to be used with a scaler having a 100-μsec dead time.

Counting Method

Disposable 3-dram vials* are used in all analyses. The samples are dissolved in 5 ml of scintillation solvent, and, when necessary, air is removed by bubbling with argon for 2–4 min. The vial is dipped into a beaker of silicone fluid (DC-550) to wet the bottom. This avoids the possibility of trapping air bubbles between the bottom of the vial and the photomultiplie-tube. The vial is inserted into the aluminum reflector (see Fig. 1) and pressed gently onto the photomultiplier tube. After replacing the lid, counting is begun immediately. Pulses from photoactivation of the soft-glass vials are avoided by setting the discriminator high enough and the high voltage (for carbon-14) low enough to reject these weak pulses.

For the performance studies, toluene-C^{14} was used as a carbon-14 standard and tritiated *n*-butyl benzene as the tritium standard. The former was standardized against a National Bureau of Standards sample of benzoic acid-C^{14}; the latter was standardized against two NBS water samples. The carbon-14 standard decayed at 4.88×10^5 dpm/ml, the tritium standard at 6.0×10^6 dpm/ml. All data are the result of counting duplicate and usually triplicate samples.

* Kimble Glass Co. screw-cap vials, 19 × 65 mm, No. 60910.

TABLE 2—Precision of Background Counting Rate

Date	*Total counts*	*Total time (min)*	*Cpm*
2/13	48	1	48
2/25	1,488	30	50
2/28	1,289	23	56
3/1	3,353	66	51
5/14	434	10	43
5/21	444	10	44
5/29	1,312	31	42
5/29	2,406	60	40
7/30	2,580	60	43

The best diffuse-reflecting coating (on the inner surface of the aluminum reflector) was a suspension of Linde Sapphire A powder in Tygon "clear" lacquer (0.5 gm/ml). This was painted on the reflector and then dried under an infrared lamp. When dirty the coating can also be replaced quite easily. Exploratory work showed that 6 gm/l 2-phenyl-5-(4-biphenylyl)-1,3,4-oxadiazole (PBD) and 100 mg/l POPOP resulted in a significant improvement in the efficiency of tritium counting over diphenyl oxazole + POPOP. Some data covering this point are shown later.

Tube Noise, Background

Preliminary tests with carbon-14 and tritium established the best discriminator setting for reducing noise, glass fluorescence and spurious pulses.

The effect of photomultiplier voltage on tube noise and total radiation background (5-ml sample of scintillation solvent) is shown in Table 1. For comparison, the data obtained several months earlier are also included. The improvement of tube noise with time at higher voltages is strikingly demonstrated. Thus, at 1,200 volts there has been about 50% reduction in noise (and of course background) over five months. This suggested that the

TABLE 3—Effect of Voltage on Efficiency and E/B Values—Carbon-14

	Oxygen present		*Oxygen removed*	
Operating voltage	*Efficiency* (%)	*E/B*	*Efficiency* (%)	*E/B*
950	34.36	1.074	45.24	1.414
1,000	52.84	1.468	61.52	1.708
1,050	67.40	1.570	73.30	1.710
1,100	77.76	1.114	82.44	1.212

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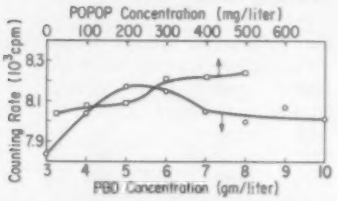

FIG. 3. Effect of PBD and POPOP concentration on counter efficiency for C^{14}

assay of tritium at low concentrations was entirely feasible on July 30 while it was useful for only moderate to high concentrations on February 13.

The excellent stability of the counter and its utility in measuring very low carbon-14 disintegration rates is demonstrated in Table 2. The small variation of the background (43 ± 2 cpm) for long counting periods indicates its freedom from spurious pulses when counting carbon-14. This stability suggests that as little as 10 cpm above background can be measured with good accuracy. The known slow response of the glow-transfer tubes used in the scaler emphasized the need for correcting for the dead time of the counter. By conventional methods (*12*) this correction was found to be 0.22% per 1,000 cpm of observed activity.

Carbon-14 Counting

Twenty-five lambda aliquots of the standard solution (25λ = 12,200 dpm) in 5 ml of the scintillation solvent were used to determine counter performance for carbon-14 samples. The counting solution contained PBD (6 gm/l) and POPOP (20 mg/l) in toluene.

Table 3 presents the effect of photomultiplier voltage on carbon-14 efficiency. The E/B value is a simple method for determining the optimum counting voltage. (E is the efficiency in percent, and B is the background counting rate.) For low counting rates, E^2/B is preferred. Table 3 shows that 1,050 volts is the optimum voltage for counting carbon-14.

The effect of scintillation solute concentration on carbon-14 efficiency was also investigated. PBD was the primary solute and POPOP the secondary solute. A plot of concentration versus activity is shown in Fig. 4. It appears that there is a slight maximum in efficiency at 5–6 gm/l of PBD. Similarly, the graph shows that about 300 mg POPOP/l is necessary for a significant increase in activity. Unfortunately at this high concentration there is a tendency for POPOP to precipitate out of solution. Therefore, a concentration of 6 gm/l PBD and 100 mg/l POPOP was selected.

Tritium Counting

Twenty-five lambda aliquots (150,000 dpm) of the tritium standard were added to 5 ml of counting solution and assayed. Table 4 shows the effect of photomultiplier voltage on efficiency. The counting solution was 6 gm/l PBD and 100 mg/l POPOP in toluene.

The powerful quenching effect of oxygen is clearly demonstrated. Improvements in efficiency of ~50% result from its removal. Furthermore, the very low efficiency of the instrument for tritium at low voltages suggests that at the carbon-14 operation voltage very little tritium is counted. Thus, it is fairly simple to determine both isotopes in a mixture by counting at two voltages. The accuracy of this analysis will depend, of course, on the ratio of the concentrations of the two isotopes (*13*).

The very weak average-energy tritium betas make the assay of this isotope particularly sensitive to changes in counting conditions. Thus, while only a nominal change in efficiency for carbon-14 is noted when varying the

TABLE 4—Effect of Voltage on Efficiency and E/B Values—Tritium

	Oxygen present		*Oxygen removed*	
Operating voltage	*Efficiency* (%)	*E/B*	*Efficiency* (%)	*E/B*
1,140	11.20	0.091	20.61	0.181
1,160	17.46	0.116	29.12	0.201
1,180	25.18	0.122	38.59	0.202
1,200	33.70	0.132	49.43	0.175

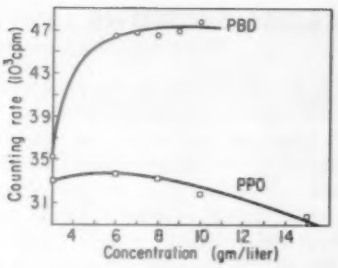

FIG. 4. Effect of solute (PBD and PPO) concentration on counter efficiency for tritium. POPOP concentration is 100 mg/liter

quantity of scintillation solute (see Fig. 3), a more pronounced effect might be observed when counting tritium. Furthermore, while slight (~4%) improvement in efficiency for carbon-14 was found when changing from PPO to PBD, it was expected that a more pronounced effect would appear when counting tritium. As shown in Fig. 4, there is a substantial gain in efficiency when using PBD over PPO.

Discussion

Since obtaining the results reported here, we have tested three other Du Mont K-1448 tubes. Two were only slightly poorer than the original tube for carbon-14 measurements. The efficiencies were in the range 50–60% at backgrounds of 60–80 cpm. This is acceptable behavior in view of the high stability of this instrument. However, they were not useable for tritium assays at room temperature.

In addition to the NBS standards used, samples were exchanged with D. R. Christman of Brookhaven National Laboratory. A sample of benzoic acid-C^{14} analyzed at Brookhaven at 4.0 μc/mg carbon was found here to contain 4.14. A second Brookhaven sample having 10.1 dpm/mg carbon showed 10.8 here. Our measurements of NBS tritium standards were compared with measurements made with a dual-channel liquid-scintillation counter at Shell Development Laboratory. The difference was less than 3%.

In analyses of unknowns, it is standard practice to use internal standards with all samples. While this introduces the necessity of a second count, the authors have assayed seventy-five unknowns in a day with no inconvenience. Substantial reductions in carbon-14 background may be achieved by the use of low-potassium vials (*14*) and an upper-level discriminator. Re-

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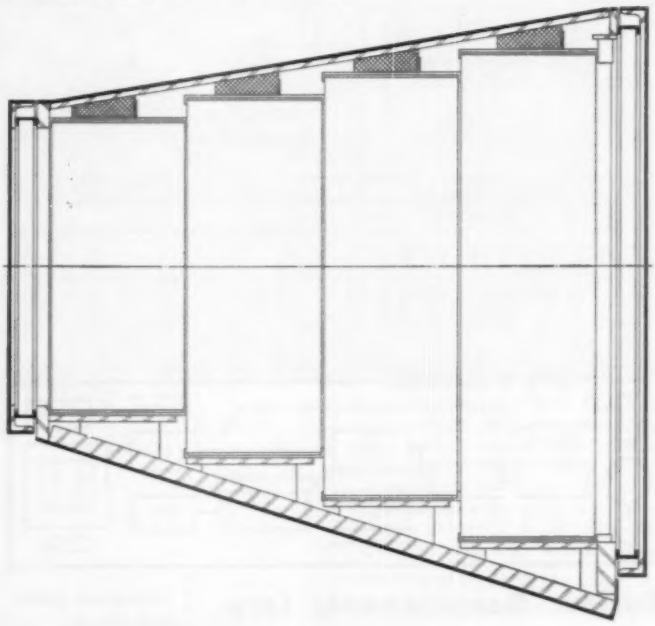

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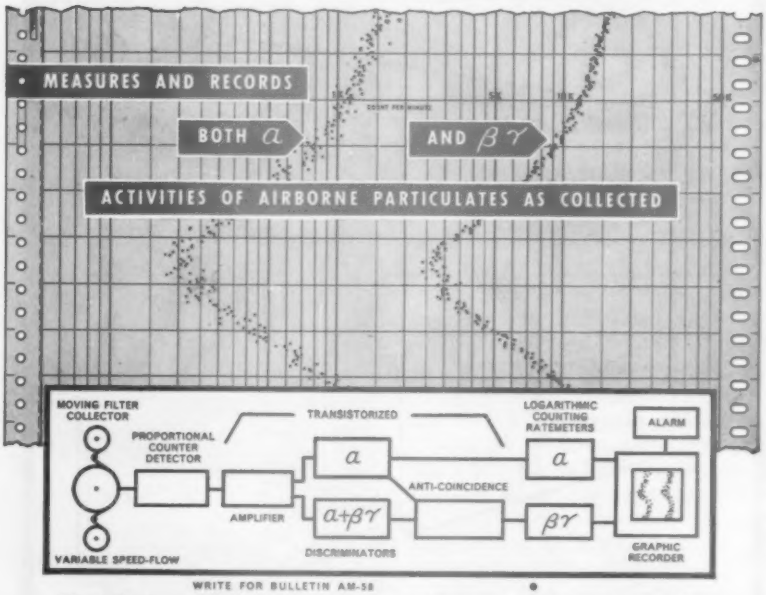

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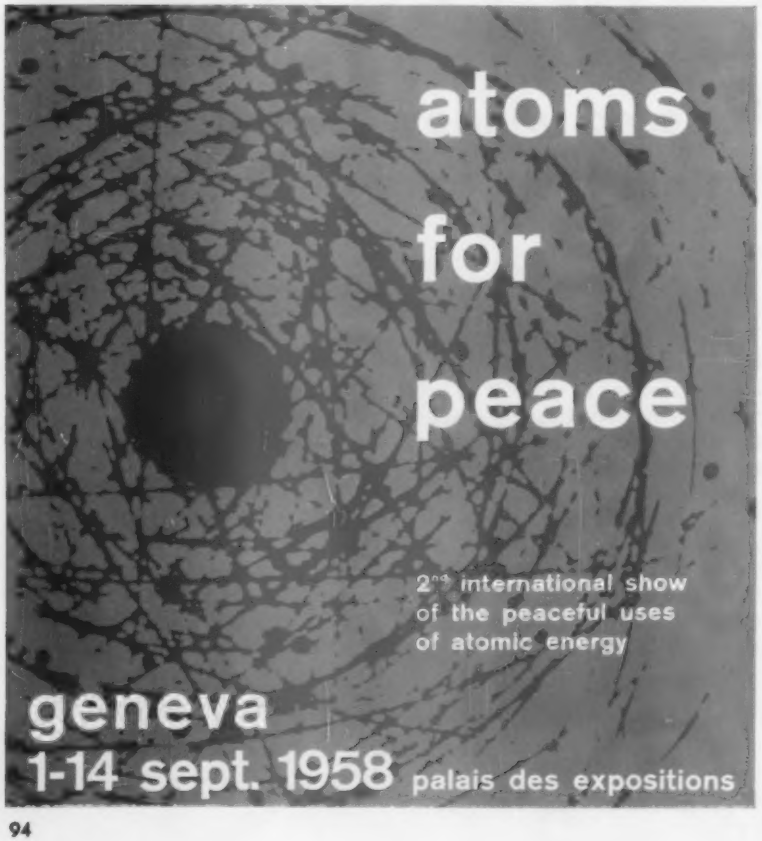

duction in tritium background must come from better photomultipliers.

Once in operation, the counter should be on continuously except for the high voltage. If the low-voltage power supply is interrupted for any appreciable length of time, at least one day is required for the unit to reach stable performance again. Furthermore, placing the counting room on a separate circuit has been effective in reducing the spurious pulse noise.

Some suggested improvements in the unit are (1) a microswitch in the lid of the lead shield so that the high voltage is cut off before the lid is removed; (2) the use of a fast scale-often bank in place of the first glow-transfer tube to reduce coincidence loss.

* * *

The authors are pleased to acknowledge the assistance of R. A. Winge in performing many of the analyses reported here.

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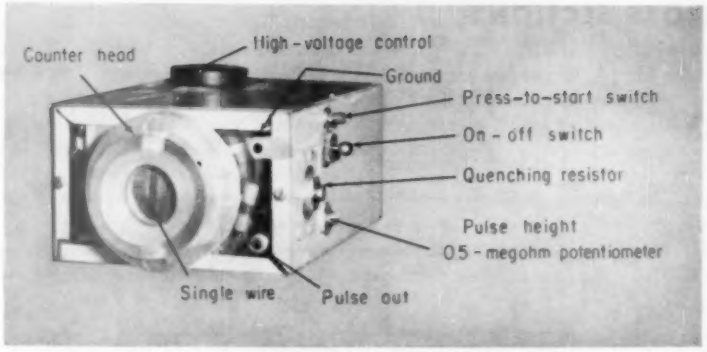

FIG. 1. Pocket-size, 3-lb 6-oz spark counter uses interchangeable counting heads for slow neutrons and underwater counting

Transistorized, Portable Spark Counter

By E. LAISK
School of Applied Physics
The New South Wales
University of Technology
Kensington, N.S.W., Australia

A portable, pocket-size spark counter (Fig. 1) with visual and aural indication has been designed to drive a ratemeter, scaler or stroboflash. Interchangeable counting heads include a special head for detecting slow neutrons and a sealed extension head for underwater counting.

Spark counters (*1–4*) have been limited by their shallow depth, low acceptance angle, long deadtime and a high working voltage. On the other hand, they are simple, windowless and sensitive to α-particles only and hence most suitable for measuring small differences in α ranges and for discriminating between various α sources (*5*). Also, a spark counter can be used as a detector for slow neutrons by means of alpha particles from the $B^{10}(n, \alpha)Li^7$ reaction (*6, 7*).

Further advantages are a very short pulse rise time and large pulse amplitudes that do not require amplification. With suitable quenching networks and optimum separation between electrodes, a relatively high counting rate can be achieved (*6*).

In recent years, many improvements have been made to the spark counter (*6, 8, 9*). An extremely high resolution time (10^{-10} sec) has been reported for

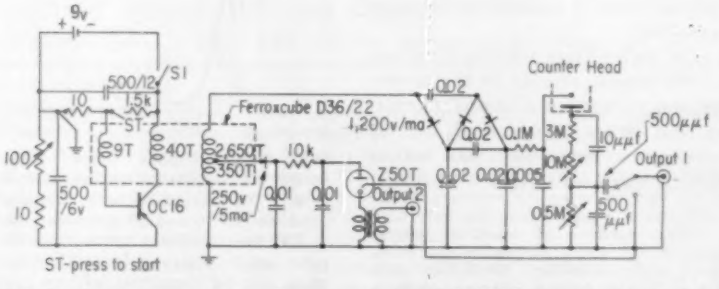

FIG. 2. Spark-counter circuit. Power supply is at left; Z50T gives visual indication; output is provided for, e.g., headphone or ratemeter

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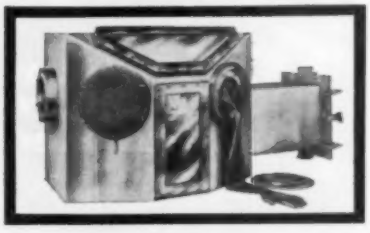

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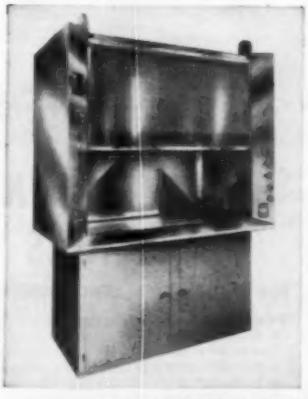

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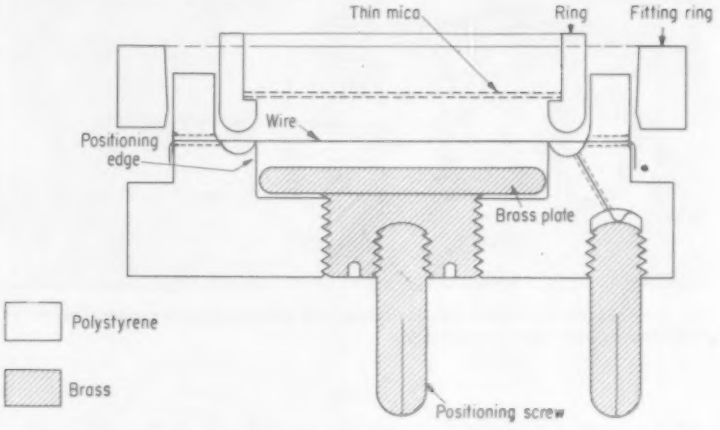

FIG. 3. Construction of counting head. Distance between wires and brass plate can be finely adjusted by screw. Wires are kept in one plane by positioning edge. Wires are locked and insulated by fitting ring and stretched by other ring. Thin foil in bottom of groove and fine wire make connection to power supply

parallel-plate spark counters operating in gas mixtures at high pressures (*9*). Sensitivity and counting efficiency have been greatly increased by multiwire systems (*5*, *6*).

Design

The spark-counter circuit is shown in Fig. 2. The power supply, a transistor d-c converter, operates from a 9-volt dry battery (300-hr useful life) and delivers 2–4 kv. The operating frequency is about 3.5 kc, the resonant frequency of the high-voltage coil. This frequency was adopted to reduce effectively the size of smoothing capacitors and for safety. No harm will be caused to the operator by occasionally touching the wires.

The coil is wound on Ferroxcube D36/22 pot core, and a compromise has been made between efficiency and step-up ratio. The output voltage can be varied from 2 kv to 4 kv for experimental purposes by means of the potentiometer. Normally, the OC16 is run well below rated power, and for a fixed voltage it can be replaced by a smaller transistor.

The high-voltage winding is tapped at 350 turns to provide for the operating d-c voltage for a miniature cold-cathode trigger tube Z50T.* This tube serves, firstly, for visual indication; it has a bluish glow. Secondly, the primary of a small step-down transformer is connected into the cathode circuit of the Z50T, and a loudspeaker, headphone, ratemeter or stroboflash can be connected to the secondary.

The construction of the polystyrene or Teflon counting head is shown in Fig. 3.

The principal parameters of the counter are: (a) the value of the quenching resistance, (b) the distance between wire and plate, (c) the diameter of the wire, (d) the applied voltage.

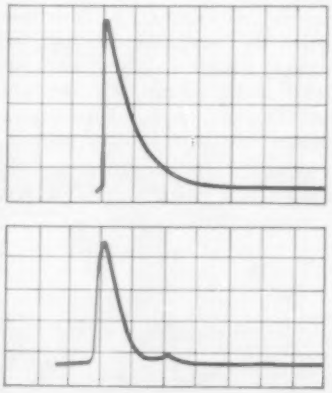

FIG. 4. Output-pulse shapes. Top, normal pulse shape (quenching network = 4 + 0.2 megohms with parallel capacitors of 10 and 50 $\mu\mu$f; time base is 100 μsec/division); bottom, shortest pulse length achieved (1 + 0.1 megohms, parallel capacitors left out and leads kept short; time base is 100 mμsec/division)

* Characteristics of miniature trigger tube Z50T: anode voltage = 175 volts, min.; starter-to-cathode breakdown voltage = 71 volts; average continuous cathode current = 2–6 ma; ionization time = 50 μsec; deionization time = 200 μsec.

They are interdependent and determine the quiescent corona current, maximum counting rate, sensitivity and pulse characteristics (*6*).

Sets of these values were found for several counting heads so that the effective voltage on the counter head remains constant over a considerable range of input voltage. The operation and reproducibility of the counter was found stable over long periods.

Counting Heads

The sensitivity and counting efficiency can be made very high in multiwire units. However, the effective voltage becomes quite critical and the corona current large.

To overcome the difficulty of uniform adjustment of the multiwire units, a fine mesh of copper on thin mica sheet was attempted by the etching method. However, the roughness of the edges limited the operating voltage range.

For detecting slow neutrons, a thin layer of borax was deposited on a thin mica sheet (0.002 in.), which was positioned in the front of the wires. Borax can be fused to mica at about 600° C; otherwise loose particles will be attracted to the plate by the strong electric field near the wires and will cause erratic counts and avalanches.

Performance

The output pulse shapes are shown in Fig. 4. With a multiwire counting head, an efficiency of 0.8% for slow neutrons was found.

* * *

The author wishes to thank C. J. Milner and C. Curnow of the N. S. W. University of Technology for their interest and R. Menere for the construction of the counting heads.

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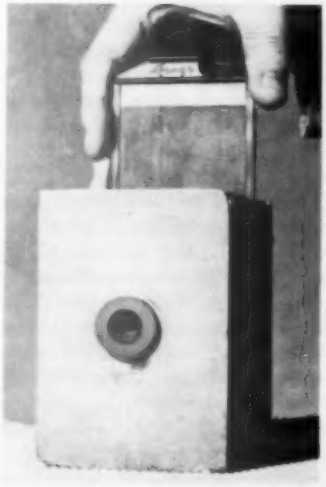

Pin-Hole Camera Locates Contamination

A pin-hole camera devised at KAPL can locate contamination in areas too "hot" for ordinary monitors. It can also survey in several hours an area that would require days with a detection instrument.

The camera, the simple pin-hole variety, consists of a lead box and uranium lens barrel to exclude stray radiation. Conventional light-recording film is nearest the lens and behind it is X-ray film; separating them is a thin lead sheet to intensify the gamma radiation. Superposition of the developed X-ray and conventional films locates the contamination (see photograph above, right). A 12-min exposure is required for light and at least 1 hr for γ-rays. A metal slide cuts off light after sufficient exposure without interfering with γ-ray exposure. Camera weight is 29 lb.

The lens barrel is made of uranium because uranium is denser than lead and can better collimate γ-rays to the $\frac{1}{16}$-in. aluminum lens inside the barrel. A pin hole 0.0135 in. in diameter in the aluminum lens admits light rays—John Payne, Knolls Atomic Power Laboratory, Schenectady, N. Y.

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A simple modification has been described by H. R. Lukens, Jr., and D. M. Seid (Shell Development Co.) to convert a single-channel pulse-height analyzer to a two-channel instrument suitable for "double-tagging" studies. The conversion is inexpensive and is applicable to most commercial single-channel analyzers.

The instrument that was modified was a Radiation Instrument Development Laboratory model 115 single-channel analyzer. In ordinary operation, the analyzer output is controlled by a lower (baseline) discriminator, an upper (channel-width) discriminator and a gate that is triggered closed by pulses of sufficient height to pass the upper discriminator ("overpulses"). Thus, only pulses that pass the baseline discriminator and do not pass the upper discriminator are fed to the output. This provides channel 1 in the modified instrument.

The instrument is modified so that overpulses are fed to a separate output, which constitutes channel 2. In the RIDL instrument, a pulse of about 20 volts is given to the gate circuit by the overpulse trigger. A coupling capacitor and attenuation network is arranged to deliver an output pulse sufficient to trigger a scaler or ratemeter (~2 volts). Since it is a high-impedance network, it does not affect circuit parameters.

The modified unit has been used to measure Cr^{51} (0.32-Mev gammas) and Co^{60} (1.1- and 1.3-Mev gammas) simultaneously. With the channels set at 19–28 volts for channel 1 and >28 volts for channel 2, pulse distribution was 52% of Cr^{51} and 9% of Co^{60} pulses in channel 1 and 4% of Cr^{51} and 66% of Co^{60} pulses in channel 2.

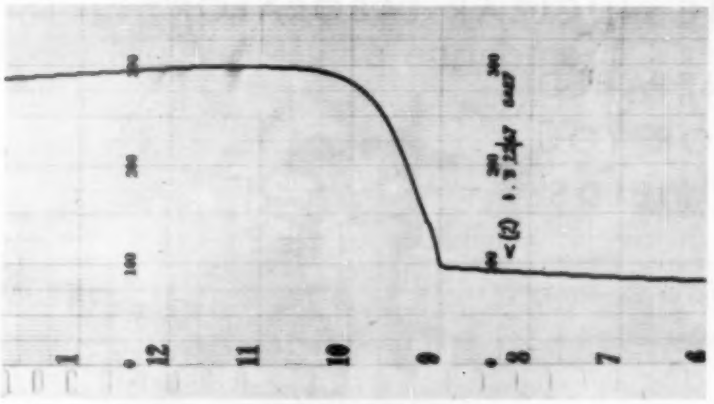
Irradiation Study Technique

Plastic replicas of pre- and post-irradiation uranium samples are used at Hanford to minimize handling.

Half-inch uranium disks are polished, etched, scribed and duplicated in cellulose acetate before being canned. After irradiation, the disks are removed from the capsules and again duplicated remotely. The replicas are then compared by optical and electron microscopy for structural changes.

Cellulose acetate can be easily applied and stripped by remote means.

NUCLEAR ENGINEERING NOTES



GRAPHITE TEMPERATURE for BEPO shows typical jump as Wigner energy release begins. Portion of trace shows temperature in ° C vs. time in hours

Wigner Energy Release for BEPO

As a postlogue to the Wigner-energy-release incident at Windscale last fall (NU, Nov. '57, 130; NU, Dec. '57, 43), the British Atomic Energy Authority has recently (March 16) staged a graphite-annealing operation on the BEPO Windscale-type reactor at Harwell. After gathering together over 500 thermocouples, 74 chart recorders and 75 engineers and scientists, Harwell proceeded to demonstrate that a properly instrumented Wigner release can be made with complete safety.

New heating method. The operation used a newly devised method of heating the graphite pile to the release temperature. The inlet air flow to the reactor was reduced to about 5% of full normal flow and was heated to 130° C by 750 kw of electric heating grids installed in the inlet duct. This heated the graphite structure up slowly over a period of ten hours to about 90° C. At this point a slow release of stored energy began and the temperature of the graphite rose, reaching a maximum of 330° C (see figure). During this period some blocks of the graphite were seen to rise sharply in temperature by about 200° C in a time period of the order of 5 min.

The zone in which the stored energy release was taking place spread slowly from the air-inlet end of the reactor to the exit end and to other radial regions. The reactor could at any time have been blown cold by turning on the main circulating fans.

New filter system. With the failure of the Windscale outlet-air filtering system still very much on its mind, Harwell took the precaution at BEPO of installing an elaborate filtration and scrubbing plant capable of removing any traces of radioactive iodine from the outgoing air. As an additional precaution BEPO was closed down for about a week from December 24, 1957 and then operated only on weekends until the energy-release experiment to allow the radioactive iodine in the fuel elements to decay.

The filter system included a bank of 28 filter frames arranged in zig-zag formation across the extract duct. Each frame contained six layers of starch-bonded oiled glass fiber. This system ensured 90% retention of particle sizes between 10 and 15 microns. A further bank of 168 Vokes filters of composite "Kompakt" (efficiency 93% for particles less than 10 microns) was also arranged across the duct.

Finally the air passed through a Vokes 55/5 absolute paper filter (efficiency 0.01% penetration of methylene blue). Similar filters were used as part of an emergency iodine scrubber device. The scrubber (which was not needed during the experiment) had caustic soda solution in towers in front of the filters to remove radioactive iodine from the outgoing air.

BNL energy release. On the other side of the ocean, Brookhaven's air-cooled graphite-moderated test reactor (which is now running at 13 Mw on enriched fuel) was annealed during a 12 hour period on May 31. In this the ninth annealing operation in the history of the reactor, the temperature in the center air gap rose to about 275° C.

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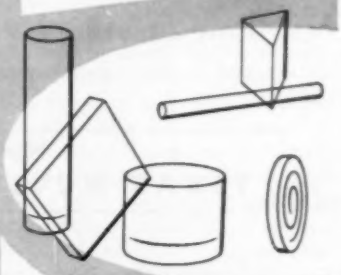

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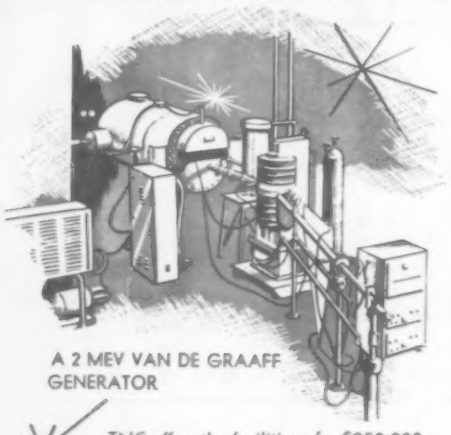

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Blending Versus Re-enrichment

By DONALD KALLMAN* and JOHN E. BRENNAN
The Babcock & Wilcox Co., New York, New York

In deciding how to reuse burned-out fuel the operator of a slightly enriched reactor can choose between two alternatives: after the depleted uranium has been processed to remove the fission products and Pu, the operator can either (a) return it to the diffusion plant to be re-enriched to its initial value or (b) blend highly enriched U with the depleted material to get the proper enrichment.

A cost analysis using the AEC's enriched U price scale shows that blending is slightly more expensive than re-enrichment. In practice, however, other advantages of blending (e.g., the possibility of using partially decontaminated spent fuel) are likely to override the small cost disadvantage.

Cost Comparison

In re-enrichment the entire batch of spent fuel would be converted from uranyl nitrate (the way it comes from the processing plant) to uranium hexafluoride; it would be run through the diffusion plant in this form and then converted from UF_6 to UO_2 for use in the reactor. With blending the spent, chemically reprocessed fuel would be converted directly from nitrate to oxide; the small amount of highly enriched fuel to be added would be purchased as UF_6, changed to UO_2 and then mixed with the rest.

The principal cost factor in re-enrichment is the cost of the diffusion-plant service. In practice one would sell the depleted uranium to the AEC and buy back the more enriched uranium, so that this cost is just equal to the difference in the two prices listed on the AEC enriched U price scale. The table shows that this difference for a reactor that takes in 3%-enriched uranium and discharges 2%-enriched uranium is about $155/kg of uranium.

In blending, the major cost item is the price of the highly enriched uranium. Using the same example, 10 gm of highly enriched uranium would be needed to enrich the 2% fuel to 3%. At $17.10/gm this comes to $171/kg of total fuel or 10% more than the cost of re-enrichment. This small difference reflects the fact that the cost of uranium per gram of U^{235} content is very nearly constant as a function of enrichment for enrichments above 2%.*

The table gives estimates for the chemical processing costs that must be added to the above. Since the amount of chemical processing is less for blending, the total costs come out even closer (about 4% difference).

The chemical conversion costs listed in the table are not yet realistically established.† The AEC will no longer perform these services when commercial sources are available, and the commercial suppliers are not yet numerous or in volume production. However, these rough estimates show that chemical conversion costs are secondary compared with the U costs. Thus the conclusion is that blending should be almost as economical as re-enrichment of irradiated uranium.

Blending Advantages

There are a number of additional factors in favor of blending.

The extra chemical steps required in the re-enriching scheme will take more time to perform than will the chemical steps in the blending scheme. Due to the great value of the material in these processes higher inventory charges may be levied during the time required for re-enrichment.

In the future there is a good possibility that composite fissionable materials including atomic mixtures of U^{235} with plutonium and U^{233}, or maybe both, are likely. If such cycles do develop, and particularly if only partial decontamination of spent fuel is required before recycling, there may be a very strong incentive, or even a necessity, to blend in highly enriched uranium rather than re-enrich through the diffusion plant cascades.

Also if the fuel recycle volume from reactors becomes large, compared to other throughput of fresh natural-uranium feed, the presence of U^{236} in the recycled reactor fuel may be a serious disadvantage in the diffusion-plant cascades.

To sum up, blending with highly enriched uranium may permanently be practiced in place of re-enrichment at the diffusion plant because the difference in cost promises to be small and the flexibility greater.

* However, by the same token, since cost per gram of U^{235} contained does, in fact, increase slightly as enrichment increases, the fissionable-material cost will always be slightly higher for blending than for re-enrichment no matter what enrichment is blended with the spent material.

† The AEC has recently announced that the charge for converting slightly enriched uranyl nitrate to hexafluoride is $5.60/kg.

Cost Comparison of Blending vs. Re-enrichment*

Re-enrichment		*Blending*	
Item	*$/kg of total fuel*	*Item*	*$/kg of total fuel*
Value of 3%-enriched U	375.50		
Value of 2%-enriched U	220.00		
Difference	155.50	10 gm U^{235}	171.00
Conversion—Nitrate to UF_6	10.00	Conversion—Nitrate to oxide	10.00
Loss during conversion	2.20	Loss during conversion	2.20
Conversion—UF_6 to UO_2	10.00	Conversion—UF_6 to UO_2	3.30
Loss during conversion	3.76	Loss during conversion	1.71
Totals	181.46		188.21
Cost/gm of U^{235} consumed	$ 18.15/gm		$ 18.82/gm

* Sample calculation for reactor that takes in 3%-enriched U and discharges 2%-enriched U.

* Deceased

NUCLEAR ELECTRONIC ENGINEERS

The term "Nuclear Electronics" is used to describe a new scientific discipline. One phase of this discipline is the study of problems resulting from the deterioration of electronics systems exposed to radiation. This problem is currently under investigation at the Hughes Research Laboratories.

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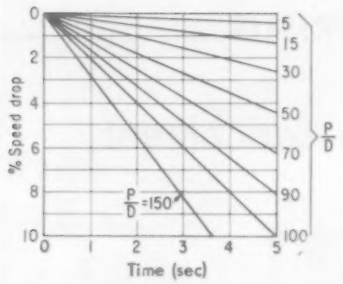


FIG. 1. Percent motor speed drop (from 1,800 rpm) vs time for 12-in diameter flywheels. The P/D isobars (where P is power in watts, D the flywheel thickness in inches) can be used to compute proper flywheel thickness for voltage stabilizer

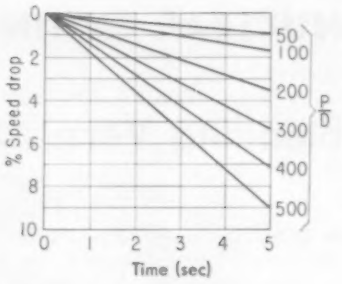


FIG. 2. Percent motor speed drop vs time for 18-in diameter flywheels. As in Fig. 1, motor is assumed to be operating at 100% efficiency at 1,800 rpm. Both graphs also assume iron or steel flywheels. As in Fig. 1, P is power, D the flywheel thickness

A Way to Stabilize Reactor Instrument Power Supplies

By J. PARNELL and C. W. SUNDIN
Minneapolis-Honeywell Regulator Co., Philadelphia, Pennsylvania

Both voltage dips and momentary power losses can cause false scrams by triggering nuclear power-plant instruments. One way to smooth out line voltage and prevent such scrams is to place an inertia-loaded motor-generator set across the line. The set is an induction motor and an alternator with a shaft-mounted exciter,* arranged so that energy stored in a flywheel generates current when line supplies falter.

The motor-and-flywheel arrangement smooths out voltage dips or momentary power interruptions. When the power supply fails, the motor decouples itself from the line without significant energy output to the remaining loads. For example, we tested a 1-hp, 2-phase induction motor with a flywheel inertia ten times that of the motor; when the motor ran with a 1.3 kw load in parallel with each phase, it slowed down from full speed at substantially the same rate as when no load was present.

Choosing the Stabilizer

Selection of a voltage stabilizer of this type for a particular installation is not particularly difficult. The motor and alternator (with its exciter) are relatively easy to select, since the criterion is the amount of power which the alternator must provide. In addition, a voltage regulator must be selected since the alternator load is not constant.

Flywheel size can be determined from Figs. 1 and 2 once the power and the efficiency of the motor-generator, the duration of the interruption and the percent tolerable speed decrease are known.

These graphs assume 100% efficiency, 1,800-rpm motor speed and cast-iron or steel flywheels. For example, assume

Power needed = 0.5 kw
Efficiency of motor generator set = 50%

Then the power input, P, to the motor-generator set is

$$P = \frac{0.5}{0.5} = 1 \text{ kw}$$

Let's say the tolerable speed drop is 9% in 5 sec. Then the flywheel thickness D can be obtained from Fig. 2. Here P/D is ~ 500, so $1{,}000/D = 500$, and $D = 2$ in. Thus a 2-in.-thick, 18-in.-diameter flywheel is needed.

The curves can be extended to 3,600-rpm systems by multiplying the P/D values by 4. They can be extended to higher P/D values by

* J. J. Gano. Power generation and distribution at air defense computing centers, *Elec. Eng.* **75**, 12 (1956).

drawing additional lines, keeping in mind that for a given interruption time, the P/D values are proportional to the speed drop.

Alternative Schemes

The inertia-loaded motor-generator set is more practical to stabilize line voltage than either synchronous condensers or battery generators. The condenser would require complicated relays, and a battery system can run into the same trouble unless the stabilizer is run off the station battery. But this may load down the station battery enough to produce transients in the battery voltage.

The inertia-loaded motor generator has its disadvantages, too, although they are not as great as the disadvantages of the condenser or battery setups. There are two disadvantages: (1) The bus to which the motor is connected must have a lagging power factor load; and (2) the motor-generator frequency is different from station service frequency. The difference in frequencies can possibly set up a beat frequency, so input and output circuits should be on separate conduits.

* * *

The authors wish to express their appreciation to Mr. Harry L. Latham for his suggestions concerning the rotating machinery.

Radiation-Resistant Motors for Nuclear Aircraft Controls

By R. C. FRIES

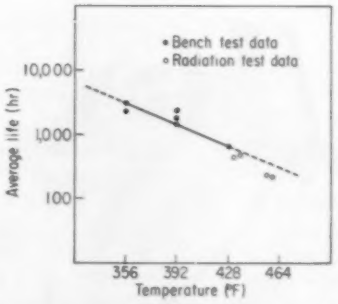
Aircraft Nuclear Propulsion Dept., General Electric Co., Cincinnati, Ohio

Irradiation tests showed that small electric motors stand up rather well to reactor radiation and high temperature—the environment to which they'd be exposed in nuclear aircraft control systems. Tests at Convair's Nuclear Aircraft Research Facility (NARF) Fort Worth, Texas, showed that temperature damaged the motors far more than limited exposure to neutrons and gamma rays.

The motors* were fabricated from materials expected to be radiation-resistant, including organic insulants and lubricants. The motor parts and their organic components were:

Part	*Organic Component*
Magnet wire	Heavy Alkanex
Slot liners	Polyurethane-coated Mylar
Slot wedges	Melamine glass
Joint insulation	Silicone glass tape
Varnish treatment	Silicone
Bearing wicking	Dacron
Lubricant	Mil-7808 B

Of 30 identical motors tested, 25 were still running after 521 hr in the NARF reactor. The radiation exposure totaled 7.9×10^{14} n/cm² and 1.5×10^{7} r of gamma rays. The average neutron flux on the motors (without attenuation correction) was 6.5×10^{5} thermal n/cm²/sec/kw and 10^{6} fast n/cm²/sec/kw. Power level was 400–500 kw.



LIFE-vs-TEMPERATURE characteristic of electric motors insulated with Alkanex (a modified polyester) and exposed to 7.9×10^{14} n/cm² and 1.5×10^{7} r of gamma rays shows that this radiation dose affects life slightly if at all

This radiation caused limited damage. Of the motor components, only melamine glass and silicone varnish showed physical changes, but none of these changes exceeded 25%. The dielectric stability of the insulants was unimpaired.

Temperature effects were more significant. Motors were run in three groups: one group at an average tem-

* General Electric 0.025-hp, 60-cycle, 120-volt a-c business-machine motors.

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perature of 356° F, another at 392° F, and a third at 428° F. The motors heated themselves to these temperatures after their fan blades were removed and their rotor diameters reduced to provide a larger airgap between rotor and stator. These modifications increased the operating temperature of the motor windings.

After preliminary bench-testing, the motors were mounted on a test panel and placed in the reactor. The total running time of the motors, including preliminary testing, irradiation and post-irradiation operation totaled 703 hr. Four of the five motor failures occurred in the group that ran at 428° F; the other motor failed from a short circuit before irradiation. Of the four failures in the high-temperature group, one was attributed to loss of lubricant, the other three to insulation melting. Since some of the motors in the 428° F group ran for prolonged times at temperatures above the softening point of Alkanex (465° F), the insulation melting is easily explained.

The lubricant was also sensitive to high temperature. Its low viscosity above 200° F resulted in considerable oil loss from bearing housings, and was directly to blame for one motor failure. Although standard procedure for accelerated-aging tests such as these recommends frequent bearing lubrication (impossible in these tests), a more viscous lubricant would be more suitable for high-temperature motor operation.

The graph (p. 103) sums up the effects of temperature and radiation on motor life as determined in this experiment. Motor life expectancy varies from 700 hr at 428° F to 3,000 hr at 356° F average operating temperature.

Recent Advances in Ultrasonic Decontamination

By ROBERT L. ROD
Acoustica Associates, Inc., Mineola, New York

Newer ultrasonic decontaminators are bigger and cheaper. A year ago they were limited to several gallons capacity—now they hold several hundred gallons.

The reason: more efficient transducers. The curie point of barium titanate—the transducer piezoelectric material—has been boosted from 105° to 140° C, with some values reported as high as 250° C.

A typical ultrasonic cleaner of circa 1954–5 was capable of cleaning objects up to 4 in. on a side in a container having a cleaning solution capacity of under a quart.* Radium, thulium-170 and cobalt-60 contamination of aluminum, brass and Monel sources and small equipment was reduced from 20,000 cpm to 100 cpm in 15 min using water and detergent as cleaning agents. Ultrasonic decontamination proved more effective than the prior method of scrubbing with soap and water and, being suited to remote operation, reduced personnel-exposure problems.

A current ultrasonic decontaminator of several hundred gallons capacity can clean objects up to 4 ft on a side or large numbers of smaller parts with equal effectiveness. The cost of this equipment is but five or six times that of the smaller 1955 model. In many nuclear applications, e.g., cleaning reactor fuel rods, many identical parts are decontaminated. It is often more economical to design special tanks to accommodate these parts.

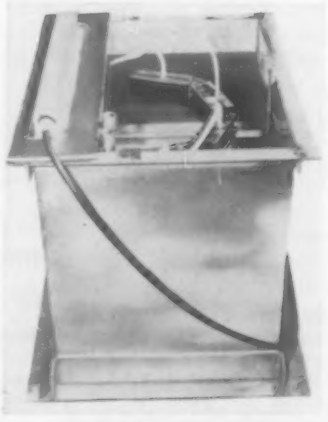

FIG. 1. Ultrasonic decontaminator for hemispherical parts

Figure 1 shows a special cleaner of a type used to decontaminate a hot object resembling a worker's safety helmet. The transducers are mounted to concentrate the energy at the surface of the hemispherically shaped part. The continuous action of the cavitation prevents the contaminating material from readhering to the part as it is withdrawn from the cleaning solution.

Another tank (Fig. 2) is designed to decontaminate 6 × 3-ft steel plates. In operation, a sheet being cleaned is remotely lowered into the tank, which is lined internally with forty transducers, twenty to a side. These transducers, which have a radiating face of 15 in², are energized by a pair of ultrasonic generators, each delivering 2 kw at the 40-kc resonant frequency of the transducers.

Radioactive salt and radioactive grease can't be removed by the same cleaning system. A water-detergent solution in a stainless-steel tank re-

FIG. 2. Tank is used to decontaminate 6 × 3-ft steel plates

* M. J. Feldman. Advantages of ultrasonic cleaning, NUCLEONICS **12**, No. 11, 65 (1954).

moves the salt, while perchlorethylene in a carbon-steel tank removes the grease. In both applications, ultrasonics has reduced cleaning time from abou. 30 min to less than 2 min and has improved quality.

Figure 3 is a sketch of an ultrasonic system now used for decontaminating fuel-rod assemblies. The tank is a large-diameter pipe mounted vertically with the lower end closed. A ring of transducers around the upper opening of the tank provides a cavitation field around the assembly as it is lowered into the solvent-filled tank. The cavitational action flushes the innermost recesses of the assembly, which otherwise are virtually inaccessible to any conventional cleaning tool.

Generally the transducers are of the barium-titanate type in which blocks of the piezoelectric material are bonded within welded rectangular stainless-steel cans. Barium-titanate transducers are available with radiating surfaces ranging from 15 to over 500 in^2 per unit, requiring driving powers of 50–1,250 watts each. In large applications, groups are driven in tandem by electronic or motor-driven high-frequency generators.

In certain applications, magnetostrictive transducers are finding considerable use, particularly when operations are conducted above the 180° F temperature limit of barium titanate. Such transducers are available in sealed assemblies that can be lowered into a tank or flange-mounted on the outer walls of the tank.

An ultrasonic footware decontaminator has been designed to remove all types of radioactive soils from protective footware. Fresh water is circulated and its level kept an inch above the soles of the feet by an overflow drain. Overflow can be fed to the waste sewer or filtered and recirculated. Detergent can be added automatically. An immersion period of 30 sec is usually satisfactory. However, this depends on the nature of the soils and the detergent.

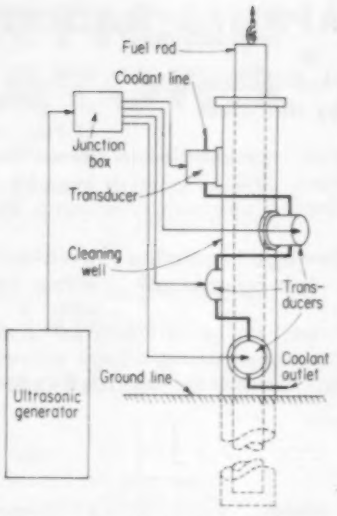

FIG. 3. Reactor fuel-rod cleaning system presently in use features water-cooled magnetostrictive transducers

A newly developed transducer snake is shown in Fig. 4. It is currently being evaluated for use in piping in a nuclear processing plant.

It is reasonable to expect that in two or three more years ultrasonic decontaminators will be capable of handling parts of enormous size in tanks of several thousand gallons capacity. We also would expect considerable advancement in the art of in-place cleaning, using transducers permanently mounted at points in liquid-filled systems where contamination tends to be most severe.

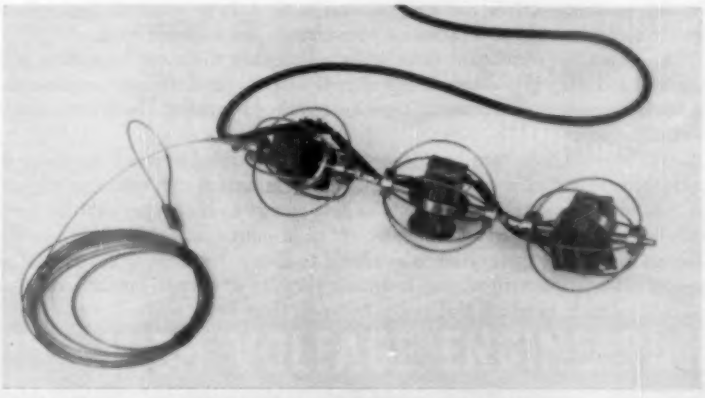

FIG. 4. Transducer snake for decontaminating piping in place

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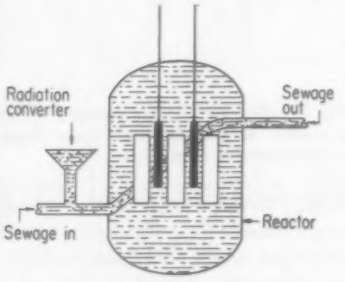
APPLIED RADIATION

Nuclides Tabulated by Half-Lives Analytical people will welcome a list of the nuclides arranged by half-lives now available as BNL 487-(T-112). It has been compiled by Elaine Daniels from information in the General Electric Chart of the Nuclides as revised to April, 1956. The list is available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C.—price $1.75.

Sewage Irradiation —Is It Economical? Every one thinks it should be economical to sterilize sewage with radiation, but no one is doing anything about it. At least it appears so at the moment. Several studies have been published.* They evaluate the radiosensitivity of bacterial organisms, the cost of irradiating with gamma rays and neutrons, the type of reactor that might do the job, etc. Altogether they lead to the conclusions that sewage can be sterilized, that some day it will be economical, but that at the moment it is not.



A typical problem in sewage-disposal economics was one that recently faced Los Angeles. Should they build a treatment plant and dump the processed sewage near shore or spend $20-million to run a 5-mile pipe out into the ocean to take care of the problem without treatment? Cost estimates for the reactor to do the job were $28-million for installation and $3,900/day for operation. The pipe was plainly cheaper.

Another study carried out by the Armour Research Foundation under the sponsorship of the Army's Biological Warfare Laboratories at Fort Detrick, Md., concluded that sterilization with radiation alone would cost 1.4¢/gal. Radiation plus reactor heat could do the job for 0.25¢/gal.

Radiation efficiency. A consideration that appears to be overlooked is the efficiency with which available radiation is used. Are there methods of delivering radiation to sewage that are significantly cheaper than the ones appropriate for food? Is the problem in irradiating a substance that is to be dumped the same as that of something that is to be used?

A constant dilemma is the search for a radiation that will penetrate pipe and vessel walls and then be efficiently absorbed in the process stream. Gamma rays get in readily, but they also pass through with a minimum of absorption. Alpha and beta particles deliver their energy effectively, but how do you get them to their target in the first place?

A possible solution? What might be a way out is shown in the figure. The stream is loaded with an appropriate nuclide and then run through a reactor. In the reactor the nuclide captures neutrons and emits alphas or betas. The nuclide is chosen to be an efficient radiation converter and to have a short-half-life product that will not produce a high level of contaminant radioactivity. B^{10}, for example, offers an n,α reaction with a large cross section. It has already seen some use as a radiation converter in brain-tumor work.

The system has significant drawbacks. Probably the most important is the danger of inducing intolerable levels of radioactivity in inorganic components of the sewage stream. But computations are required to evaluate both potentialities and limitations.

Instantaneous dose rate in this system is proportional to $\phi n \sigma E / t_{1/2}$ where ϕ is thermal neutron flux, n is atomic density of the radiation converter (atoms/cm³), σ is reaction cross section, E is alpha or beta energy available per capture, and $t_{1/2}$ is the half-life of the product nuclide. If $t_{1/2}$ is short compared with the transit time, an immediate integration is available to give a dose rate $\propto \phi n \sigma E$. In any case, an integration with respect to transit time, in which activation takes place, and holdup time, in which alphas and betas do their work, will tell the total dose.

*G. M. Ridenour, E. H. Armbruster, *J. Am. Water Works Assoc.* **48**, 671 (1956); H. N. Lowe, Jr., *et al*, *J. Am. Water Works Assoc.* **48**, 1363 (1956); D. L. Narver, Jr., *Civil Eng.* **27**, 618 (1957); *Radioactivity at Work* (Nuclear Science and Engineering Corp., Pittsburgh, Pa., January, 1958)

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A NUCLEONICS Survey—

Gamma-Irradiation Facilities in the United States

By R. HOBART ELLIS, Jr., *Associate Editor*, NUCLEONICS

About 40 high-level isotopic irradiation facilities are currently in use by schools and industrial and research establishments of the United States. They include a total of ~ 350,000 curies of Co^{60} and nine spent-fuel installations. These are among the results of a NUCLEONICS survey of such facilities. Some of the results are tabulated on the facing page.

The survey supplements an earlier bibliography of similar information (NU, Nov. '57, p. 170). No attempt has been made to include medical installations, particle-irradiation facilities or other sources of high-energy photons such as accelerators and X-ray generators.

Many for public use. Of the facilities listed 20 indicate that they are available for public use, and 27 say that they are not. In some cases the answers were qualified to indicate that while the facility is generally used only by the owner company, there is no real objection to inquiries for service irradiation.

Only eight facilities indicate that clearance is required for their use. Twenty-nine can accommodate classified experiments.

Largest source of the group is the Oak Ridge storage facility (NU, March '57, p. 98), currently rated at 200,000 curies of Co^{60}. This facility is no longer available for public use.

Rapid Development

The irradiator field is in a state of rapid change and development. So many companies have established their own facilities and so many of these offer service irradiations to outsiders that the Atomic Energy Commission has bowed out of the business. As of last March 31 it no longer offers gamma irradiations where industrial facilities are adequate for the purpose. Co^{60} prices have been reduced and placed on a new schedule that gives advantage to large-quantity orders. The current range is $2–5 per curie, replacing a former range of $2–10 per curie (NU, Sept. '57, p. 32). The price of Cs^{137}, often suggested as a substitute for Co^{60} and widely used in Britain, has been reduced by a much larger factor—from $14 to $1–2 per curie (NU, May '58, p. 27). This isotope will soon be available in increased quantities from Oak Ridge.

At least one irradiator is planned to use more Co^{60} than all current sources combined. This High Intensity Food Irradiator (HIFI) will be installed at the Quartermaster Corps's Sharpe General Depot at Lathrop, Calif. It is likely to contain ~2-million curies. The current annual Co^{60} production rate in the United States of 300,000 c/yr will have to be increased several fold if it is to supply irradiators of this magnitude. Additionally an AEC-sponsored study will evaluate the potential demand for large irradiators, and this may inspire further construction (NU, April '58, p. 24).

Lack of Standardization

A serious difficulty in surveying the field is a need for vocabulary. It is probably impossible to find commonly recognized units for size, prices and irradiation capacity.

Consider, for example, the matter of size. The curie of Co^{60} is adequate for cobalt sources, but it does not permit comparison with photon radiation from other sources. The situation becomes further complicated if one tries to include particle accelerators. The survey questionnaire asked for the radiation power in watts, but few of the people answering had this figure available.

Prices for service irradiations are another potential source of confusion. They have probably not become important to irradiation people yet, but they will be more important when radiation becomes a commercial commodity. Few people sent prices in terms of the units offered: $/hr, $/hr /ft² and $/megarad-lb.

Irradiation capacity would be an interesting figure of merit, but no generally acceptable figure appears to be available to describe it. Few facilities were prepared to estimate their outputs in megarad-lb/hr.

A set of suggested standards. It appears possible and desirable to define a set of quantities that would make irradiation facilities comparable. Preferably the set would include all types of irradiators—accelerators as well as isotopic sources. A usable set would appear to be the following: total radiation power (watts), potentially useful radiation (total radiation power less the amount *inevitably* lost by absorption in source and shielding), radiation efficiency (per cent of the useful radiation delivered to the sample in a particular geometry), radiation cost (dollars per megarad-lb). Other useful units could be derived; for example, the irradiation rate or production capacity in megarad-lb/hr. The irradiation field is growing at a rate that indicates the need for some standardization of this kind.

Facility	*Location*	*Source strength, date (Curies of Co^{60} except as otherwise noted)*	*Maximum dose rate (10^6 r/hr)*	*Maximum volume (ft³)*	*Public use?*	*Clearance required?*	*Classified experiments?*	*Personnel, policy, facilities**
Argonne National Laboratory	Lemont, Illinois							
Rack M-1		(12 MTR elements)	3.5	1.47	Yes	No	Yes	PCOR
Rack M-2		(8 MTR elements)	0.075	5.2	Yes	No	Yes	PCOR
Storage rack		(0–12 MTR elements)	0.3	1.47	Yes	No	Yes	PCOR
Atomics International	Canoga Park, Calif.	1,100 Sept. '54	1.5	1	No	No	Yes	PCLR
Battelle Memorial Institute	Columbus, Ohio	2,400 June '58	1	~700	Yes	No	Yes	PCOMLR
Brookhaven National Laboratory	Upton, New York	~25,000	1.25	1	No	No	Yes	PLR
Budd Co., Nuclear Systems Div.	Philadelphia, Pa.	10,000–15,000†	0.75	320	Yes	No	Yes	PCWTMBL
California Research Corp.	Richmond, Calif.	590 Nov. '57	0.24	0.014	No	No	Yes	PCL
Cities Service R & D Co.	Cranbury, N. J.	~5,000 May '57	1.6	500	No	No	No	PWMLR
Columbia University	New York, N. Y.	1,400 Sept. '57	0.4	12	No	No	No	PC
Continental Oil Co.	Ponca City, Okla.	(8 MTR elements)	0.5	3	No	No	No	PWTOML
Dugway Proving Ground	Dugway, Utah							
Spent-fuel facility		(8 MTR elements)	2	1.0	Yes‡	Yes	Yes	PBR
Large Co^{60} facility		3,160 April '58	0.225	0.5	Yes‡	Yes	Yes	PR
Small Co^{60} facility		30 April '58	0.003	0.05	Yes	Yes	Yes	PO
Electronic Products Co.	Mount Vernon, N. Y.	~80	—	—	Yes	Yes	Yes	PCOM
Esso Research & Engineering Co.	Linden, N. J.	17,600 Nov. '57	10	440	No	No	Yes	PWMBLR
B. F. Goodrich Co.	Brecksville, Ohio	1,378 June '55	0.19	0.54	No	No	No	LR
Hanford Atomic Prod. Operation	Richland, Wash.							
Co^{60} dry facility		2,000 —	—	—	No	Yes	Yes	PCL
Reactor-fuel-storage basin		— —	1.5	1.2	No	Yes	Yes	PCWML
		(Fuel elements)	—	3	No	Yes	Yes	PCL
		Co^{60}¶	10	—	No	Yes	Yes	PCL
Hughes Research Laboratories	Culver City, Calif.	500 Mar. '57	0.4	0.04	Yes	No	Yes	PC
Inland Testing Laboratories	Morton Grove, Ill.	62,000 Oct. '57	10	4,000	Yes	No	Yes	PCWOMBLR
Knolls Atomic Power Laboratory	Schenectady, N. Y.	3,440 1952	1	20	No	Yes	—	—
Linde Co.	Tonawanda, N. Y.	4,280 April '58	2.5	400	No	No	Yes	PWM
Magnolia Petroleum Co.	Dallas, Texas	15 June '57	0.008		No	No	No	PM
The Martin Co.	Baltimore, Md.	5,150 Oct. '57	0.38	4	Yes	No	Yes	PCOLR
MIT, Dep't of Food Technology	Cambridge, Mass.	850 Nov. '54	0.22	0.05	No	No	No	PCOML
National Reactor Testing Station	NRTS, Idaho	(Fuel elements)	10	1,600	Yes§	No	No	PO
University of Michigan	Ann Arbor, Mich.							
Fission Products Laboratory		2,800 June '58	0.265	700	Yes	No	Yes	PCOLR
Phoenix Laboratory		5,100 June '58	1	20	Yes	No	No	PCWTMLR
Minnesota Mining & Mfg. Co.	St. Paul, Minn.							
Spent-fuel facility		(4 MTR elements)	1	5	No	No	Yes	PCMLR
Co^{60} facility		600 Sept. '5	0.6	0.1	No	No	No	PCLR
Naval Air Material Center	Philadelphia, Pa.	1,400 Jan. '58	0.5	~0.06	No	No	No	P
University of Notre Dame	Notre Dame, Ind.							
Ghormley-Hochanadel		1,200 Apr. '58	0.6	0.0018	No	No	No	P
Underground		1,193 Aug. '57	0.6	0.0018	No	No	No	P
Oak Ridge National Laboratory	Oak Ridge, Tenn.	~200,000	2.5	1	No	No	Yes	PR
Radiation Applications, Inc.	L. I. City, N. Y.	1,350 Dec. '56	0.36	6.75	Yes	No	Yes	PCMLR
Rensselaer Polytechnic Inst.	Troy, N. Y.	900 Apr. '58	0.3	35	Yes	No	No	PCWMLR
Sinclair Research Laboratories	Harvey, Illinois	(4 MTR elements)	1.5	1	No	No	No	WMBL
Socony Mobil Oil Co.¶	Pennington, N. J.	— —	2	—	No	No	No	WMLR
Southwest Research Inst.	San Antonio, Texas	8,800 Jan. '57	20	180	Yes	No	Yes	PCWM
Stanford Research Inst.	Menlo Park, Calif.	2,500 May '58	0.6	1	Yes	No	Yes	PCMBLR
Stevens Inst. of Technology	Hoboken, N. J.	300 Oct. '56	~0.17	1.5	No	No	Yes	PCOLR
The Texas Co.¶	Beacon, N. Y.	~27,500 June '58	1		No	—	—	PWML
Worcester Foundation for								
Experimental Biology	Shrewsbury, Mass.	156 Mar. '58	—	—	Yes‖	No	No	PW
Wright Air Development Center	Wright-Patterson A. F. B., Ohio	21,000 Oct. '57	0.8	1.8	No	No	Yes	PWTM

* P = personnel to conduct experiments, C = contract research, W = viewing window, T = closed-circuit television, O = other viewing equipment, M = manipulators, B = conveyor, L = liquid-flow equipment, R = refrigeration equipment.

† Varying amounts of Co^{60}. Facility can handle any amount up to 25,000 curies.

‡ If time is available, public use can be arranged through the Commandant, Quartermaster Food and Container Institute, 1819 West Pershing Rd., Chicago 9, Ill.

§ AEC may grant permission for experiments that private facilities can not handle.

¶ Facility is not yet in operation.

‖ Facility is available for biological research. Arrangements can be made through Dr. Ralph Dorfman at low cost or none.

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TECHNICAL ADVANCES

No Charge Separation Found in Neutrons

Although neutrons have no net charge, some theories postulate the existence of separate positive and negative charges within the neutron itself. Electron-scattering experiments have demonstrated the charge distribution in protons, but separate charge sites cannot be found in neutrons. Researchers at Columbia, U. of Chicago, Brookhaven and Argonne measured the interaction between electrons and neutrons, and found that the total forces could be explained by the so-called Foldy effect. (Prof. Foldy of Case Institute explained neutron-electron scattering as a result of the interaction of the neutron's magnetic moment with the electron's field.)

If there were separated charges inside the neutron, a further neutron-electron force should be observed, but experimenters found no evidence of it.

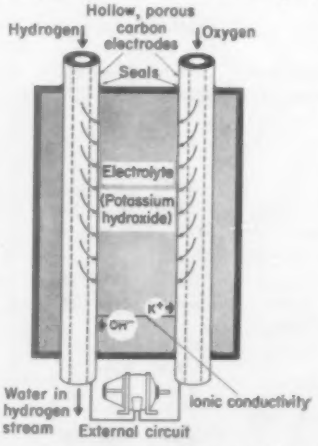
Direct Conversion with Fuel Cells?

A new fuel cell that generates electrical energy from the combination of hydrogen and oxygen offers reactor engineers two potential services: recombination to remove hazardous hydrogen-oxygen mixtures and direct conversion of nuclear energy to electrical power.

The cell, developed by National Carbon Co., is intended to furnish electrical power for remote radar stations without the electrical noise of generators. As shown in the diagram, you just push hydrogen and oxygen (or air) into the cell and extract an electric current resulting from the two reactions

$$O_2 + 2H_2O \rightarrow 4OH^- - 4e^-$$
$$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$$

An unnamed catalyst in the porous electrodes and potassium hydroxide, present as an electrolyte, promote the reactions. The net result is the burning of hydrogen with oxygen to form water with an energy release of 68.4 kilocalories/mole.



The new cell has an efficiency of ~70% and an essentially infinite life. It is basically a high-current, low-voltage device, but the designer can adjust the geometry and combine cells in series to accommodate a variety of needs. With optimum design it is believed that it can produce as much as 1 kw per cubic foot of volume.

For a rough estimate of the potential value to a reactor we can look at EBWR, in which dissociated oxygen appears at a rate of 154 cm³/sec when the reactor is operating at 20 Mw(th). Rough computation shows that ~4,000 watts is available if we recombine this with 100% efficiency. Several improvement factors are immediately available if we think in terms of using this power. A factor of ~25 should be available if we go to an aqueous homogeneous system where fission fragments as well as knock-on protons contribute to radiolysis. (If we use actual values for SUPO at Los Alamos* the ratio is 16.) Also we might increase the radiolysis to a maximum instead of taking pains to reduce it, as has been done so far. Altogether, then, one could talk of such power as

$$\frac{4{,}000 \times 25}{20} = 100{,}000 \text{ watts(electrical)}/20 \text{ Mw(th)}$$

This is not efficient conversion in itself, but it is relatively free power since our thermal megawatts are still nearly undiminished. The cell's conversion efficiency is impressively better than the usual heat-to-electricity conversion.

*L. D. P. King in "Proceedings of the International Conference on the Peaceful Uses of Atomic Energy," vol. 2, p. 383 (United Nations, New York, 1956)

THERMONUCLEONICS

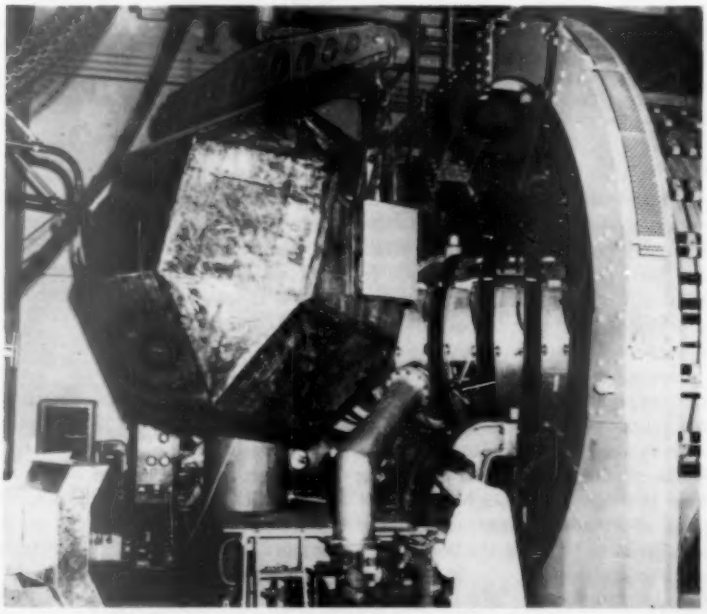
Microwaves Aid Fusion Research

High-temperature plasmas such as are necessary to the generation of controlled thermonuclear power can be studied with microwave techniques. Such important properties as the electron density and temperature and their spatial and temporal variations can be measured.

Fundamental to the use of microwaves for plasma diagnostics is an understanding of the electromagnetic properties of plasmas as a function of microwave frequency. Three frequency regions of interest can be distinguished—(1) from d-c to a characteristic frequency given by the collision frequency in the plasma, (2) from there to the Langmuir-Tonks plasma frequency, which depends directly on electron density being given by $(n_e e^2/\epsilon_0 m_e)^{1/2}$, and (3) the region above the plasma frequency. At low frequencies the plasma conductivity is high (a 10,000,000° C plasma is as good a conductor as copper, and the conductivity gets higher as the temperature is further increased). In the second region, the ionized medium behaves like a waveguide beyond cutoff—a wave cannot propagate and, if generated externally, is totally reflected at the boundary of the plasma. At high frequencies, above the plasma frequency, the medium acts like a low-loss dielectric—the dielectric constant and the index of refraction vary with frequency and are less than unity. The transition between the last two regions is very sharp and leads to a marked change in the microwave properties of the plasma—from totally reflecting to highly transparent. Measurements of index of refraction in this transitional region (a phase-sensitive bridge operated at fixed frequency is used) provide a value for the electron density, n_e.

Actual measurements prove to be more difficult than the preceding theory might make it seem. For one thing the plasma frequency is high; for ~ 4-μ pressures, the electron density is about $10^{15}/cm^3$, for which the corresponding plasma frequency is 300 kMc, the wavelength 1 mm. This is the very frontier of the microwave art. Another consideration is that fusion devices have strong magnetic fields to provide containment, and these cause the plasma to behave anisotropically, with strong resonances at the electron cyclotron frequency. Nevertheless meaningful diagnostic measurements have been made, generally transmission measurements using a microwave beam, since the more common cavity techniques are not applicable.

Based on a paper by Mark A. Heald of Project Matterhorn to be published in the 1958 IRE National Convention Record, part 9.



SOMETHING NEW HAS BEEN ADDED TO ZETA. Polyhedral structure suspended in mid-air houses directional neutron counter used to study operation of UK's Zero Energy Thermonuclear Assembly (NU, Feb. '58, p. 90)

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BOOKS

Radiation Effects on Materials, Vol. 1

ASTM Special Technical Publication No. 208 (American Society for Testing Materials, Philadelphia, 1957, v + 190 pages, $4.75).

Reviewed by E. E. BALDWIN, Mechanical Metallurgy and Metallography, Knolls Atomic Power Laboratory, Schenectady, New York.

With the continued development of nuclear power plants for the production of commercial power, there is an increasing need on the part of the designer and materials engineer for information concerning the effect of radiation upon the engineering properties of materials. This information is becoming increasingly available by the increased declassification of reports of technical work in this field.

One of the major problems, once the technical information is available, is the dissemination of this information to those who have need for it. ASTM Special Technical Publication No. 208 is a collection of 16 technical papers presented at a Symposium on Radiation Effects on Materials held in Los Angeles, September 20, 1956, and sponsored by the American Society for Testing Materials and the Atomic Industrial Forum. This is the first of a series of similar meetings that will be held to discuss the problems involved in the use of engineering materials in radiation fields of nuclear reactors.

The information is presented by people who are recognized authorities in the field of radiation damage. The papers cover six general areas of radiation effects which are of concern in reactor engineering.

In a nuclear reactor, fuel, structural and moderator materials are subjected to bombardment by massive particles of high energies, primarily neutrons. This bombardment results in displaced atoms. G. J. Dienes reviews the theory of radiation-damage mechanisms, such as vacancies, thermal spikes, displacement spikes, etc., and compares the theory with observed experimental results.

The investigation and determination of radiation-induced changes in materials involve techniques not generally encountered in the evaluation of engineering materials. Radiation facilities, dosimetry and mechanics of testing are described by J. E. Whitney, R. Berggren, V. P. Calkins and A. W. DeAgazio.

Fuels and moderators generally receive the greatest amount of radiation and, because of their specific characteristics, undergo major changes in properties. Bowen, Carter and Kittel, Paine and Chiswik describe the effects of radiation on uranium, graphite and uranium-zirconium alloys in three separate articles.

Changes in metallic structural materials, both ferrous and nonferrous, caused by radiation are of particular concern, especially in determining the safe operating conditions of a reactor. Five papers dealing with this subject by authors such as Castleman, Leeser and Wilson are included.

The changes in the properties of organic materials as reviewed by Sisman and Bopp are of particular interest since these materials can undergo drastic changes in properties as a result of not only neutron but other types of irradiation.

Finally, the effect on specifications and standards of the use of engineering materials in radiation fields is reviewed by Sisman for organic materials and Wilson for metals.

In summary, this publication is an initial review of the additional problems to be encountered by the designer and materials engineer in applying materials in radiation fields. It should be, and undoubtedly will be, followed by similar books so that the problems encountered in radiation can be recognized and dealt with effectively.

Radiography in Modern Industry, 2nd ed.

X-Ray Div., Eastman Kodak Co. (Eastman Kodak Co., Rochester, 1957, 140 pages, $5.00).

Reviewed by GEROLD H. TENNEY, Los Alamos, N. M.

The first edition of "Radiography in Modern Industry" appeared in 1947. It quickly became an important reference book and was used as such in practically all industrial radiographic laboratories and other places where its contents could be of value.

Because of the great demand, this publication was out of print for the last two years. Very recently the second edition was published by Eastman Kodak Company. When comparing these two editions it can be seen that great effort and intense study have been given to bringing the book up to today's requirements.

As in the past, this new edition will also serve two purposes. It will be a good source of information on industrial radiography for management, metallurgists, designers and radiographic technicians. It presents the fundamentals of industrial radiography clearly and understandably. Secondly, it will be the reference book on the sensitometric characteristics of Eastman Kodak films, which are of great value to the supervisor and the researcher in the field of industrial radiography.

The second edition has also added sections on the use of isotopes; contains good tables for the selection of films as a function of the type of material, its thickness and available energy of radiation; lists storage conditions of films with regard to the presence of cobalt-60 and iridium-192 (the first edition had the respective tables with regard to radium). It furthermore discusses such subjects as microradiography, fluoroscopy, photoradiography, high-speed radiography, stereoradiography and X-ray diffraction. It contains also a handy table on the sensitivity of film with regard to radiation monitoring.

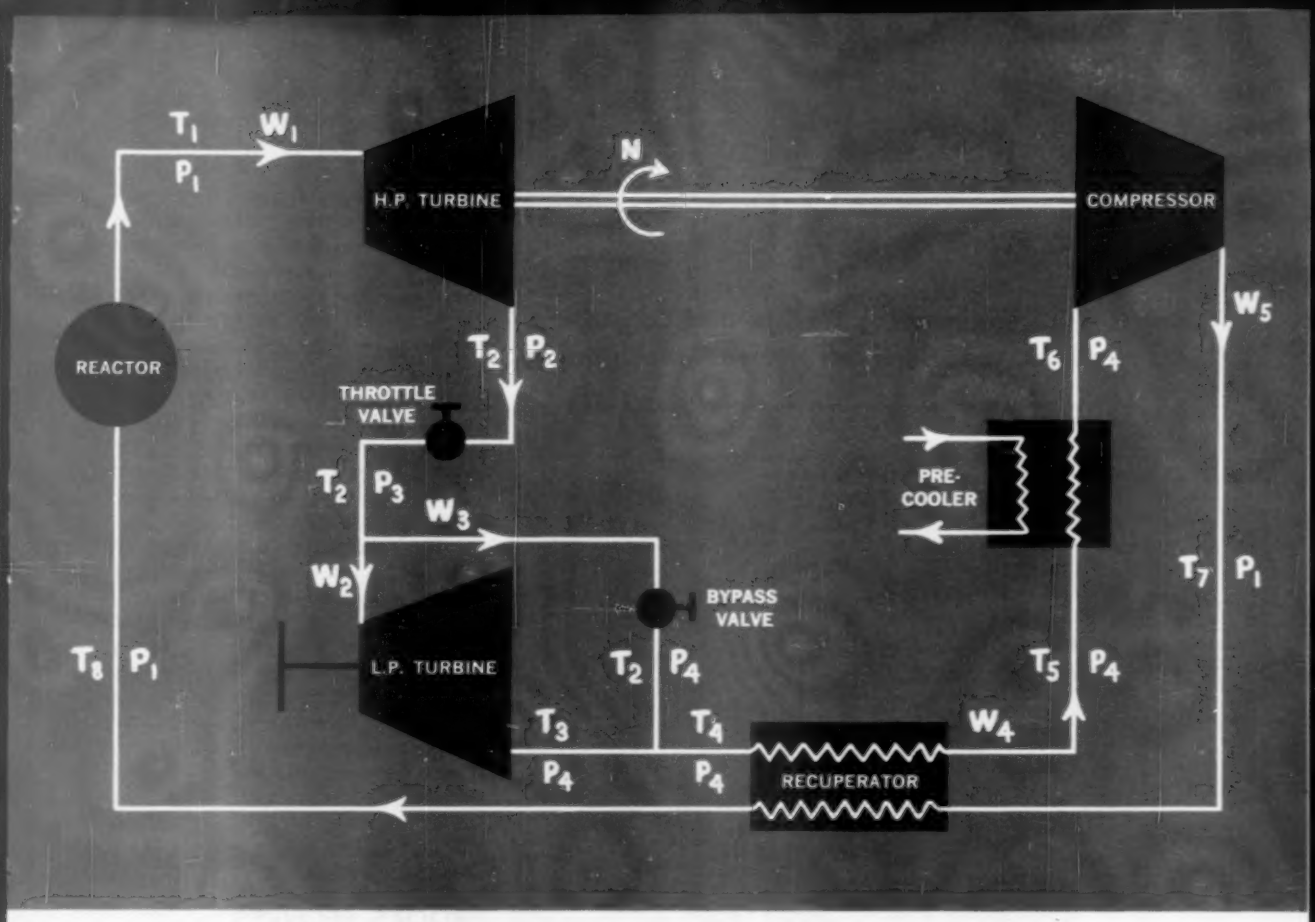
Advances in Radiobiology

Edited by G. C. de HEVESY, A. G. FORSSBERG and J. D. ABBATT (Charles C Thomas, Springfield, Ill., 1957, xvi + 503 pages, $15.50).

Reviewed by SHELDON WOLFF, Biology Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

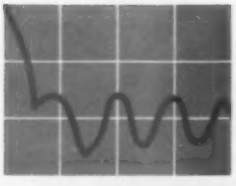
In August, 1956, the Fifth International Conference on Radiobiology was held in Stockholm, Sweden. Biologists, biophysicists and physicians from all over the world, including Russia and China, attended the conference to present scientific papers and to exchange ideas with their colleagues in this important biological field.

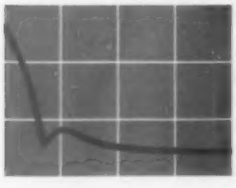
"Advances in Radiobiology" contains all the papers, along with the pertinent discussion, presented at the meetings. The three major symposia, (a) Modifications of Systemic Irradiation Damage (Protection and Recovery), (b) The Radiation Effects on the Hematopoietic System, and (c) Induced Mutations: Mechanisms and Implications, included 20-min papers as well as 10-min papers. Other subjects, such as the Initial or Primary Chemical Effects of Irradiation, Biochemical Irradiation Effects on Enzymes and Other Cellular Constituents, Physiological and Morphological Irradiation Changes, The Time Factor in Radiobiology, Studies on the Distribution of Isotopes in Tissues, Alpha-Particle Irradiation of Single Cells, and



Digital analysis tests reactor system

...without spending a nickel on hardware





The problem was to evaluate performance of the complete reactor power system design, shown blocked out in preliminary form above.

It was natural for Ford Instrument nuclear engineers to turn to the digital computer for this. They have two of them on hand—one with accessories for differential analysis—as well as experienced programmers. Ford also has access to the vast computing facilities of Remington Rand Univac Division of Sperry Rand. The flexibility, high speed and accuracy of digital techniques were especially applicable to this type of engineering analysis.

Partial results of digital analysis are shown in the two available power vs. time curves at left. They show the effects of a change in throttle and bypass valve settings. Initial analysis revealed the poorly damped oscillatory curve at top left. After a simple system modification, reanalysis produced the smooth change and quick settling of the lower curve. *All without a nickel spent on hardware!*

Reactor system simulation is only one of the nucleonic activities at Ford Instrument Co. Others include: Design of a complete closed-cycle gas-cooled reactor; development of fuel elements, including high temperature studies; manufacture of control rod drive mechanisms (e.g., those used in the submarine *Seawolf*); control rod position indicators; magnetic and transistor amplifiers for nuclear applications; and studies of control rod and reactor materials. In addition, Ford Instrument is conducting numerous feasibility and experimental studies in the nuclear field, including the application of digital techniques to reactor control.

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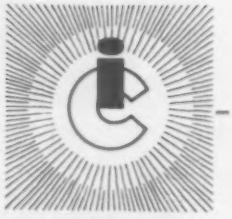

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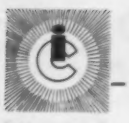

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BOOKS

Department starts on page 112

Radiation Genetics, were also represented by 10-min papers.

An extensive view is presented of the current status of work in the exciting field of radiation protection and recovery. Not only the protective work with chemicals but also the new field of radiation recovery brought about by replacing the irradiated animal's bone marrow with bone marrow from a nonirradiated animal is covered. Another exciting development presented in this book is that it now seems possible to modify radiation-induced mutations.

The book contains a comprehensive outlook of the work being performed on an important frontier of science. However, it must be remembered that these papers were presented at an international meeting of specialists, and, therefore, the papers are highly technical. Research workers in the field of radiation biology will find the book essential. Other scientists may find the book extremely interesting as a guide both to the scope of radiation biology and to the approaches being taken in this field.

BOOKS RECEIVED

Einfuhrung in die Messtechnik der Kernstrahlung und die Anwendung der Radioisotope, by Heinrich Fassbender (Georg Thieme Verlag, Stuttgart, xii + 223 pages, $8.85). The student will find this book a clear and extensive introduction to radioisotope technique. The expert will be interested to see the extent to which German science is making an independent effort in the isotope field. Four main sections are devoted to basic atomic physics, measurement techniques for nuclear radiations, applications of radiation-measuring techniques and radioisotopes, and radiation protection.

Safety Techniques for Radioactive Tracers, by J. C. Boursnell (Cambridge University Press, Cambridge, Eng., 1958, xii + 68 pages, $1.75). Probably the biggest problem in health physics is to disseminate basic information to people who need small quantities of it. This book fills the bill. The essential precautions are spelled out. Appendices list useful figures like dangerous levels and maximum permissible amounts. But detailed matter is left for other authors to put in books for experts. A final chapter

is a detailed list of do's and dont's for the laboratory worker. If every radioisotope technician could pass a satisfactory-reading test on this little volume, his supervising health physicist could feel quite secure concerning the safety of his charges.

ALSO OF NOTE

A Directory to Nuclear Data Tabulations. Major compilations of experimental and theoretical data in basic nuclear physics and chemistry are described. The directory was prepared by K. Way and R. C. Gibbs at the recommendation of the National Academy of Sciences-National Research Council under the auspices of the AEC. 185 p. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.70.*

LETTERS

Fission Confusion

DEAR SIR:

I find in Data Sheet No. 24, "Fission-Product Yields from U, Th and Pu" (NU, April '58, p. 78), that a number of errors appear in the edited version:

p. 78—the last sentence at the bottom, left should read: "The other two figures show fission-product distributions from thermal-neutron fission of U^{233} and Pu^{239} and from fission-neutron fission of Th^{232} and U^{238}."

p. 80—in the bibliography, in refs. *5* and *7*, change Table 1 to Table 2, and in ref *6*, change 1942 to 1492.

Table 1—the last footnote should give the I^{131} yield as 2.3%, not 2–3%; in refs. *5* and *7*, change Table 1 to Table 2.

Table 2—next-to-last sentence of introduction should read: "Parentheses indicate nuclide probably occurs in fission but has not been so observed"; in ref. *9*, change 696 to 693 and add: "summary of Canadian mass-spectrometric data"; in ref. *13*, add after et al.: "mass-spectrometric data"; in chain 111, vertical solid arrow should be directed from 74-s Ag^{111m} to 7.6-d Ag^{111}; in chain 133, ref. *43* should be *42*.

—SEYMOUR KATCOFF
Chemistry Department
Brookhaven National Laboratory
Upton, N. Y.

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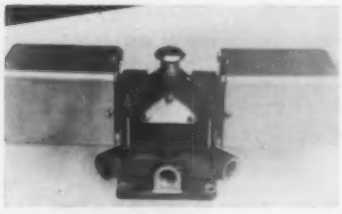
Kett Designs and Develops Reactor Components

This 6-year-old firm recently moved into a new 20,300-sq-ft laboratory and plant where it is continuing to design and develop specialized equipment for the atomic-energy field—seal-weld cutting machines, remote-handling equipment, neutron collimators and control mechanisms, among others. Four different seal-weld cutting machines were designed and developed for the Shippingport reactor, each severing a specific seal. The one shown above is for the pressure-vessel-closure seal. Typical of remote-handling equipment is a manipulator for use in the maintenance of the steam generators of the Pennsylvania Advanced Reactor being designed by Westinghouse Electric Corp. for the Pennsylvania Power & Light Co. The manipulator reaches into either of two 13-in. access openings to repair any of 1,550 radioactive, slurry-carrying tubes. A neutron collimator was designed by Kett for narrow-beam neutron-shielding tests in the Tower Shielding Reactor at Oak Ridge. The unit is remotely controlled and can be rotated or inclined to traverse any pattern desired.—Kett Technical Center, Inc., Pompano Beach, Fla.



Solenoid Valve

Model P/N 220155 plug-in valve (above) is four-way, three-position, solenoid-actuated unit rated at 100 psi and operated by 115 v, 60 cycles a-c. It has been tested for several million cycles of operation without malfunctioning. This valve will withstand surge pressures of at least 250 psi.—Whittaker Controls Div., Telecomputing Corp., 915 N. Citrus Ave., Hollywood, Calif.

Bonding Material

"Interact" is process that, through eutectic reaction, bonds aluminum to aluminum and other similar and dissimilar nonferrous metals to each other. It is available in three forms: Interact-S is intended for T joints, butt joints and other exposed joints; Interact-E is made for joining broader areas and Interact-G is intended for low-temperature joining and for other large surfaces. The joining operation can be accomplished manually by using torch or by conveyor techniques for mass production.—Intertectics Inc., Northfield and Forbes Rds., Bedford, Ohio.

Electrostatic Generators

Model CD 600-4 is compact 600-kv unit yielding regulated, stabilized voltage on flexible cable to supply ions or electrons to accelerators. Output voltage is continuously variable from 0 to 600 kv; maximum current at any voltage is 4 ma. Polarity: negative (type N) positive (type P), reversible (type R). When current varies, and for fixed setting of controls, voltage variations are 2.4 kv/ma. Fluctuations with periods up to a few seconds are ± 5 kv. Drift, after thermal equilibrium has been reached, is 0.0005/hr. Internal capacitance is ~ 500 $\mu\mu$f.

Samtron 50 is a 50-kv high-stability test set designed for overpotential, nondestructive, d-c testing. Output voltage is variable from 0 to 50 kv continuously (Samtron 50 A) or step by step (Samtron 50 B) in 1,000-volt steps with voltage setting to within 2% of true value. Output current of both is 0.5 ma (max). Polarity is negative with respect to ground. Regulation is >0.5 v. Internal capacitance is 0.001 μf. Also available is model K 300-1, a 300-kv power supply and model K 150-2, a 150-kw electrostatic generator.—Cosmic Instruments, Inc., 50 Broadway, New York 4, N. Y.

Air Monitor

Monitor will detect alpha, beta and gamma radiations in samples from as many as twenty rooms. Measures ion-chamber current to 3×10^{-14} amp. Colored lights indicate what particular room is being monitored. Audible alarms as well as a potentiometric recorder and/or controller can be connected to the instrument.—Process Instruments Div., Beckman Instruments Inc., 2500 Fullerton Rd., Fullerton, Calif.

Drawbench

A 1,000-lb hydraulic draw bench (above) has 5-ft length of draw and variable drawing speeds.—Fenn Manufacturing Co., Newington, Conn.

High-Temperaure Balls

Precision balls that will operate at elevated temperatures are made of T-1, T-2, T-5, M-2, M-10, M-50, Cobenium, modified 440, Stellite and Inconel. Other materials can be supplied upon request. Metal balls are made to tolerances as close as ± 0.00001 in.—Hartford Steel Ball Co., Inc., West Hartford, Conn.

Linear Actuator

Lineatrol is for high-precision applications where linear motion must be proportional to control signal. Lineatrol's gear motor has built-in potentiometer to produce remote indication of position. Positioning accuracies of ±0.004 in. are provided for a 10-in. stroke with greater accuracies for shorter strokes. Control signal can originate from any transducer (3–15 psi, 0.5–5 ma or variable frequency). Output from the lineatrol is through precision rack and pinion with thrust forces up to 1,000 lb and wide variety of stroke lengths and rates.—The Jordan Co., 3235 W. Hampton Ave., Milwaukee 9, Wisc.

High-Speed Scaler

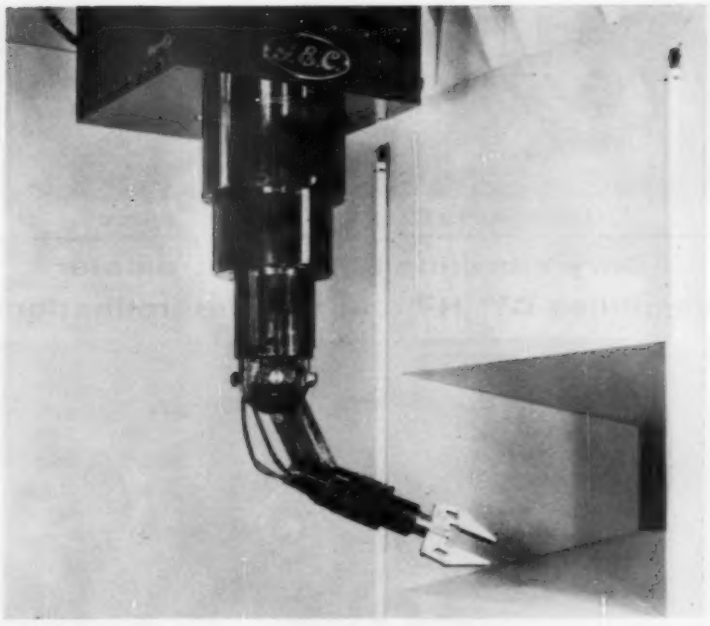
Containing a high-voltage power supply, Multiscaler II has stable discriminator calibrated at input from 50 mv to 2 v. Resolving time is ~5 μsec. Capacity of 99,999 counts is indicated on five cold-cathode Dekatron glow tubes.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Tritiated Thymidine

Radiochemically pure tritiated thymidine (HTDN) in sterile aqueous solution is available immediately in standard vials with specific activity of 300–400 μc/millimole: 5 mc (1 mc/ml); 0.5 mc (1 mc/ml); 250 μc (0.5 mc/ml).—Schwarz Laboratories, Inc., 230 Washington St., Mt. Vernon, N. Y.

Wire Covering

Zippertubing protects cables, wires and controls from certain effects of nuclear radiation. Made of lead-saturated glass cloth with a vinyl surface, waterproof Zippertubing can be zipped off and destroyed when contaminated. With wall thickness of 0.015 in., it is available in all sizes from ⅜-in. i.d. up, in increments of ⅛ in. and in lengths from 25 ft.—The Zippertubing Co., 752 S. San Pedro St., Los Angeles 14, Calif.



GEC Remote Power Manipulator

The usual mechanical linkage between the manipulator and its control console has been eliminated in this new design capable of handling objects weighing up to 750 lb. The manipulator is powered by radiation-resistant, variable-frequency, 3φ, induction motors fitted with integral electromagnetic brakes. Variable-frequency current is supplied from the console by sets of variable-speed, d-c motors coupled to generators. Speed variation is provided by a magnetic amplifier in the armature circuits. The control windings of the amplifiers are fed from potentiometers that are coupled to two control sticks. The degree of displacement of the manipulator elements is proportional to the speed of the corresponding stick movement.—General Electric Co., Ltd., Magnet House, Kingsway, London W. C. 2, England.

Density-Measurement System

System measures and/or controls fluid density, specific gravity, percent solids or related quantities independent of flow rate and pressure. Depending on process and material measured, long term accuracies of ±0.001 specific gravity or better are obtainable. Built-in standardizing circuits maintain accuracy and calibration, and any component, except radiation source or detector, can be replaced without affecting calibration.—Industrial Nucleonics Corp., 1205 Chesapeake Ave., Columbus 12, Ohio.

Small 100-kc Counter Tube

Type 7155 is equipped with three output cathodes in a T-5½ bulb. It can be used in portable and airborne equipment for both visual and electrical readout.—Sylvania Electric Products Inc., 1740 Broadway, N. Y. 19, N. Y.

Nuclear Instruments

Hand and clothing monitor measures both sides of both hands simultaneously for alpha and beta contamination by means of four scintillation counters. Clothing monitor's alpha probe consists of scintillation counter feeding logarithmic ratemeter, and beta-gamma probe uses halogen-quenched G-M tube. **Corona power supply** has been designed for use with photomultipliers, G-M counters and other applications requiring accurate voltage at low current. Maximum output current is 100 μa and stability ratio is 100:1.—EMI Electronics Ltd., Hayes, Middlesex, England.

Nuclear Battery

Model K nuclear battery, which can deliver higher currents and is safer than strontium-90 models, uses krypton-85, an inert gas that is not absorbed by the

Cary / instrument abstracts

Applied Physics Corporation/Pasadena/California

Cary Vibrating Reed Electrometer simplifies C^{14}, H^3 and S^{35} determinations

DETECTS AS LITTLE AS 10^{-12} CURIES—The high sensitivity and high precision of the Cary Model 31 Electrometer permit minimum amounts of costly "tagged" materials to be used in radioactive isotope studies, saving enough to pay for the instrument in a short time and materially reducing the hazard to living experimental subjects.

This greater sensitivity, plus the development of simplified experimental procedures, make the Cary Model 31 particularly valuable in determination of C^{14} and H^3 in biological and chemical samples. With these new techniques, the smaller samples may be used and the use of a precipitate with its inaccuracies and time-consuming preparation is eliminated. Instead, samples are directly converted into a gas which can be measured with an ionization chamber and a Cary Model 31.

The ionization chamber and vibrating reed electrometer offer the only convenient accurate method of measuring radioactivity of CO_2-air mixtures in flowing systems, such as are encountered in *in-vivo* studies.

One research group led by Dr. Bert M. Tolbert has had considerable success in applying these procedures to a wide variety of samples and research problems, including studies of animals.

NEW REVIEW PAPER

Dr. Tolbert, now at the University of Colorado, has authored a 46-page paper covering detailed procedures for C^{14} and Tritium assays, ion-chamber theory, samples and sample preparations, combustion of organic compounds to CO_2, design and construction of ion chambers and measurement of ion chamber currents and approximate calibration data. Copies of the paper are available from Technical Reports Section, Department of Commerce, Office of Technical Services Washington 25, D.C., for $1.25 each. When requesting a copy, please ask for Bulletin UCRL-3499.

OTHER USEFUL APPLICATIONS

Measurement of radioactivity is only one of many applications where the Model 31 can be used advantageously. For example, amplification and measurement of ion currents in mass spectrometry, pH determinations, precise measurements of small charges, currents, or voltages from a high impedance source can all be made faster, simpler, less expensively and far more accurately using the Model 31.

BRIEF SPECIFICATIONS OF THE MODEL 31

Accuracy—Measurements reproducible to within 1%. Accuracy limited only by the accuracy of the recorder, potentiometer, or meter used.

Reliability—No grid current, greater freedom from zero drift. Much more rugged than other types of electrometers.

Stability—Open circuit input; less than 6×10^{-14} coulombs rms short period noise; less than 5×10^{-17} amperes steady drift. Short circuit input; less than 0.02 mv rms short period noise; less than 0.2 mv per day steady drift.

10 standard ranges—Ranges provided on the Model 31 are 1, 3, 10, 30, 100, 300, 1,000 mv, and 3, 10, 30 volts. The output of the Model 31 will operate a 1 ma recording milliammeter or a standard recording potentiometer.

Accessories—Ionization chambers, recorders and various special modifications and accessories are available for all types of electrometer uses.

A new catalog on the Cary Model 31 is available. Write for your copy today to Applied Physics Corporation, 362 West Colorado St., Pasadena 1, California. Ask for Data File K9-78

PRODUCTS & MATERIALS

Department starts on page 116

body. It is small ($1\frac{7}{16}$ by $\frac{7}{16}$ in.), lightweight (22 gm), has operating and shelf life of ~10 yr, current rating of 10–1,000 μμa (~5 times that of Sr^{90} batteries), open-circuit potential of several thousand volts, linear charging rate to several hundred volts. It can also be made in larger sizes with 10^{-8}–10^{-7} amp current ratings.—Patterson, Moos Div., Universal Winding Co., Inc., 90–28 Van Wyck Exwy, Jamaica 18, N. Y.

Industrial *p*H Gear

Model 28A *p*H meter (above) incorporates isopotential control system to effect fully automatic temperature compensation. Circuit and feedback system provides stability of ±0.02 in *p*H per 24-hr period.—EIL Instruments, P. O. Box 801, Philadelphia 5, Pa.

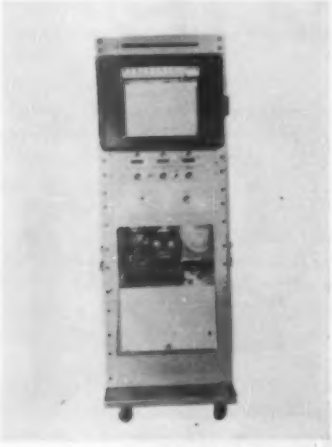
Ultrasonic Equipment

Ultrasonic processing equipment uses transducer element constructed mainly of solid metal sections joined to stainless-steel radiating surfaces by welded studs. Self-contained stainless-steel Sonitanks range in size from 6 qt to 50 gal. For larger installations, transducers can be built into all-welded, hermetically sealed, immersion Sonicells for use in existing tanks. These are made in sizes from 100–300 sq in. of radiating surface.—General Ultrasonics Co., 67 Mulberry St., Hartford, Conn.

Precision Pulse Generator

Model PPG-256 precision pulse generator uses mercury relay for generation of positive or negative pulses at 60 cps. Output pulse amplitude can be varied over 100-v range in 256 discrete steps with ratio accuracy of

0.1%. Amplitude stability is 0.05% after 30-min warmup.—Tullamore Electronics Laboratory, 6055 S. Ashland Ave., Chicago 36, Ill.



Electronic Integrator

Developed for use in chromatographic applications unit is equally adaptable to other industrial processes where it is desirable to have measured variable integrated. Counting rate is 2,400 or 1,200 or 600 cpm at full-scale reading (selective by manual switch); accuracy is ±1% at point of reading. —Wheelco Instruments Div., Barber-Colman Co., Rockford, Ill.

Survey Meter

Model GB-1 gamma/beta log/linear radiation-survey meter features fast response time, 0–1-mr/hr linear scale, two 3-decade ranges from 0.5 to 500 mr/hr and 0.5 to 500 r/hr, mercury-battery power, 300-hr-continuous or 1-yr-intermittent life and is energy independent to within 10% from 80 kev to 1.2 Mev.—Riggs Nucleonics Corp., 717 N. Victory Blvd., Burbank, Calif.

Fluid-Density Gage

Model ASR-3 measures fluid density, specific gravity or per cent solids in liquids with full-scale range as narrow as 0.05 units and precision of ±2% of range at temperatures to 350° F.—The Ohmart Corp., 2236 Bogen St., Cincinnati 14, Ohio.

Remote-Handling Tool

Model RHT-60 remote-handling tool is newly available in either 3-ft or 5-ft handle assembly with four different jaw attachments. Four special mounting plates can be used to store jaw attachments.—Atomic Accessories, Inc., 244-02 Jamaica Ave., Bellerose 26, N. Y.

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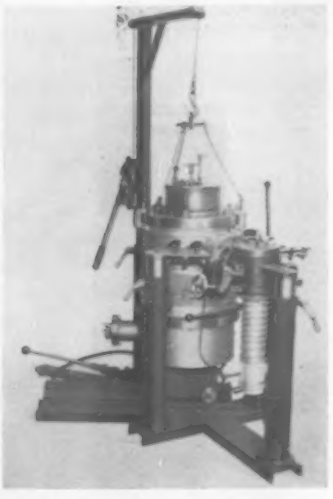
PRODUCTS & MATERIALS

This article starts on page 116



Vacuum Furnace

Model F-9 vacuum furnace is capable of attaining temperatures in excess of 2,000° C and has capacity of 10 lb of steel or volume equivalent if crucible is to be tilt-poured and 25 lb if bottom-plug is used. Pumping system can reach 1×10^{-4} mm of Hg in 18 min and 3×10^{-5} mm finally.—Kinney Mfg. Div., The New York Air Brake Co., 3529 Washington St., Boston 30, Mass.

LITERATURE AVAILABLE

Plastic phosphors, the scintillation performance of which remains stable over years of application, is subject of 2-p Bulletin S-100-1.—Crystals, Inc., 123 Wooland Ave., Westwood, N. J.

Deuterium-labeled compounds are listed in 4-p catalog.—Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

Cerium, lanthanum, neodymium and other rare-earth metals and alloys in ingot, rod, pellet, turnings or powder are covered in file folder.—New Process Metals, Inc., 45-65 Manufacturers Pl., Newark 5, N. J.

"Vacuum Furnaces" is title of Data Sheet 660.—Vacuum Equipment Div., F. J. Stokes Corp., 5500 Tabor Rd., Philadelphia 20, Pa.

Lithium, cesium and rubidium are covered in 24-p brochure with up-to-date facts and figures, including current prices, principle users and producers.—

Montgary Explorations Ltd., Toronto, Ontario, Canada.

Dysprosium-Oxide Data Sheet 501 lists some physical, chemical and high-temperature properties.—Research Chemicals, Inc., 170 W. Providencia St., Burbank, Calif.

Nuclear instruments and accessories are given in new 4-p Price List 58.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

DEKATRON, a cold-cathode glow transfer tube for counting, timing and control applications, is described in 2-p reprint.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Dye-penetrant inspection kit is offered in 4-p brochure.—Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill.

"Progress in Nuclear Medicine" is title of 32-p booklet that includes 12 articles of interest to all users of radiopharmaceuticals.—Abbott Laboratories, North Chicago, Ill.

High-vacuum components, equipment and systems, are given 16-p product summary and price list.—National Research Corp., 70 Memorial Drive, Cambridge 42, Mass.

Fuel-element fabrication facilities are described in 5-p bulletin.—D. E. Makepeace Co., Pine and Dunham Sts., Attleboro, Mass.

Diaphragm seals are described in 2-p Bulletin 250.—Brooks Rotameter Co., P. O. Box 432, Lansdale, Pa.

"Isotopes and Isotope-Labeled Compounds" is title of 15-p Price List "C."—Bio-Rad Laboratories, 800 Delaware St., Berkeley 10, Calif.

Castings for valves and fittings for nuclear power plants are discussed in 4-p reprint that places emphasis on fundamental design principles and foundry quality control.—Cooper Alloy Corp., Hillside, N. J.

Laboratory apparatus, including chromatographic equipment, are described in 12 p. catalog.—Arthur S. LaPine & Co., 6001 S. Knox Ave., Chicago 29, Ill.

"Your New Atomic Power Plant" is title of 16 p. brochure meant for dis-

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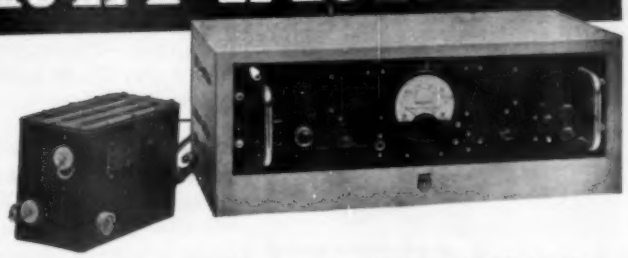

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PRODUCTS & MATERIALS

Department starts on page 116

tribution in Central Utilities area (Iowa, Minn., Neb., N. D., S. D., Wisc., etc.).—Pioneer Service & Engineering Co., 231 S. LaSalle St., Chicago 4, Ill.

Globe valves are described in 20-p. Catalog Section B-2.—Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.

"Feed Materials for Nuclear Power" is title of 16-p. oversized brochure describing feed materials plant.—Davison Chemical Co. Div., W. R. Grace & Co., Erwin, Tenn.

Electronic circuitry is described in 9-p. folder.—Beck's Inc., 300 E. 5th St., St. Paul 1, Minn.

Pyrometer supplies, including thermocouple assemblies and components, are described in 52-p. Catalog Gl00-8.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Ave., Philadelphia 44, Pa.

"British Nucleonic Instruments 1957" is title of 175-p. book that includes classified index and technical data.—Scientific Instrument Manufacturers' Association of Great Britain, 20 Queen Ann St., London W. 1, England.

Super-alloy tubing is described in 10-p. Bulletin 70.—Superior Tube Co., 1552 Germantown Ave., Norristown, Pa.

Carbon-14 compounds available from stock are given 2-p. price list.—Volk Radiochemical Co., 5412 N. Clark St., Chicago 40, Ill.

"Metallurgical Applications of Rare Earths" is title of 42-p. compilation of abstracts prepared in survey covering ten years of literature from both U. S. and foreign sources.—Davison Chemical Co. Div., W. R. Grace & Co., P. O. Box 488, Pompton Plains, N. J.

Technical papers available include "Reactor Hazards Analysis," "Vessel Design for Explosive Mixtures," "Fragment Effects on Structural Elements" and "Nuclear Safety."—Holmes & Narver, Inc., 828 S. Figueroa St., Los Angeles 17, Calif.

Thermocouple wire and extensions are listed in 8-p. Catalog 32.—Thermo Electric Co., Inc., Saddle Brook, N. J.

Nuclear engineering services are depicted in 4-p. brochure.—Burns & Roe, Inc., 160 W. Broadway, New York 13, N. Y.

Pulse handling instruments are listed in short-form catalog.—Rutherford Electronics Co., 8944 Lindblade St., Culver City, Calif.

Tritium-labeled compounds are given price list.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Fuel-element fabrication facilities are described in 4-p. Bulletin GEA-6762.—General Electric Co., 1 River Rd., Schenectady 5, N. Y.

Venturi meter tubes, their recovery characteristics, formulae that determine their design and typical calculations are described in 32-p. Bulletin 110-Pl.—Builders-Providence, Inc. Div., B-I-F Industries, Inc., 345 Harris Ave., Providence 1, R. I.

Proportional counter is described in 2-p. Data Sheet PC-58.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Flow meter engineering data are covered in 22-p Bulletin F1607.—The Bristol Co., Waterbury 20, Conn.

Radiochromatogram scanner is subject of 4-p. Publication "Nucleus" 14.—Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.

Gamma-switch applications are shown in 4-p. pamphlet.—Isotope Developments, Ltd., Beenham Grange, Aldermaston Wharf, Berkshire, England.

Stainless steel fittings are described in 8-p. booklet.—Vanton Pump & Equipment Corp. Div., Cooper Alloy Corp., 201 Sweetland Ave., Hillside, N. J.

Applied research services offered are described in 12-p. brochure.—Booz-Allen Applied Research, Inc., 430 Green Bay Rd., Kenilworth, Ill.

Rare earth metals are listed in combination data sheet and price list.—Research Chemicals Inc., P. O. Box 431, Burbank, Calif.

Radiation meters for safety monitoring and measurement are described in 4-p.

pamphlet.—Universal Atomics Div., Universal Transistor Products Corp., 36 Sylvester St., Westbury, N. Y.

INDUSTRY NOTES

During a recent visit to the U. S., Prof. Niels Bohr was presented with a pair of master-slave manipulators by the officers of **Central Research Laboratories, Inc.**, Red Wing, Minn. The equipment will be installed at the Institute for Theoretical Physics at Copenhagen, Denmark. The presentation to Prof. Bohr was made "in appreciation and recognition of contributions he has made to science and humanity."

Acoustica Associates, Mineola, N. Y., opened their fourth plant recently. Located in Culver City, Calif., the new plant will provide more than 6,000 sq ft of space for the production of ultrasonic instruments, including liquid-level sensors.

Tide Co., Louisville, Ky., has announced the decision to expand the scope of its operation to include heavy aluminum fabrication for the nuclear science and engineering field. Tide facilities at Jeffersonville, Ind. are experienced in handling all types of fabrication requiring ¼-in., and heavier, gage stock.

Hamner Electronics Co., Inc., Princeton, N. Y., has announced the appointment of **McCarthy Associates,** Pasadena and Palo Alto, Calif., as representatives for its line of nuclear instruments.

Fenn Manufacturing Co., Newington, Conn., has been awarded a large contract by **General Electric Co.** for GE's Aircraft Nuclear Propulsion project at Cincinnati, Ohio. The contract includes three tandem rolling mills and special material-handling equipment.

Radiation Counter Laboratories, Inc., Skokie, Ill. has recently appointed **Electromechanical Products, Ltd.,** Agincourt, Ontario, to represent them in Canada.

Nuclear Chemical Co. which started producing radiochemicals labeled with carbon-14, tritium and sulfur-35 in mid-1957, has changed its name to **Isotope Chemical Co.,** Chicago, Ill.

Nuclear Engineering Corp. has moved its engineering and administrative departments to 2925 N. Broad St., Philadelphia, Pa., where its production department is located.

Baird-Atomic, Inc., Cambridge, Mass., has appointed **Radionics, Ltd.,** Montreal, Canada as Eastern Canadian representative for its line of atomic instruments and systems.

The opening of a West Coast sales office has been announced by **Sylvania-Corning Nuclear Corp.,** Bayside, N. Y. Marketing manager for the western region will be James O. Vadeboncoeur, formerly of the Atomic Power Div., **Westinghouse Electric Corp.** Mr. Vadeboncoeur was supervisor of central production, planning and control of nuclear core manufacturing at Westinghouse's Bettis Plant during the fabrication of the Mk I core for the *USS Nautilus.*

Atomic Associates, Inc., New York, N. Y. will expand its representation of the **Baird-Atomic, Inc.** line of atomic instruments to include the entire U. S. except for the mid-central section. Atomic Associates also represents the **New England Nuclear Corp.,** radiochemicals; **Packard Instrument Co., Inc.,** liquid scintillation spectrometers for tritium and carbon analyses; **Pacific Electro-Nuclear Co.,** pulse-height analyzers; **R. S. Landauer Jr. & Co.,** radiation exposure devices; **Atomic Accessories Inc.,** radiation-laboratory equipment; and, announced recently, **Acoustica Associates, Inc.,** ultrasonic decontaminating equipment.

The Chalk River transistorized 100-channel pulse-height analyzer, called the "kicksorter," will be manufactured and sold in the U. S. by the Cincinnati Div. of **Bendix Aviation Corp.** under a licensing agreement with its Canadian subsidiary, **Computing Devices of Canada, Ltd.**

Consolidated Electrodynamics Corp., Pasadena, Calif, and **Hitemp Wires, Inc.,** Westbury, Conn. have signed a nonexclusive licensing agreement giving Hitemp the right to manufacture and market ceramic-coated wire using Ceramicite, which possesses properties for resisting extreme heat conditions.

Radiation Instrument Development Laboratory, Inc., Chicago, Ill., is expanding its facilities to provide larger experimental and production spaces.

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• **Case Institute of Technology** is considering the construction of a test reactor under the Atomic Energy Commission's proposed program to sign long-term contracts for space in such facilities. AEC, in advising Congress that it would need clarification of its ability to negotiate such contracts, named Case as the best prospect under a build-and-rent program. The Commission needs space in both engineering and materials testing reactors to implement its plans to double the effort on the nuclear fuel cycle. It prefers to encourage the building of privately-owned facilities rather than construct government reactors.

• **The American Nuclear Society** has established an annual graduate student award in memory of Mark M. Mills, associate director of the California Radiation Laboratory, Livermore, before his death in a helicopter accident in April. ANS president Chauncey Starr, general manager of Atomics International, said the Mills award would seek to recognize "the outstanding graduate student working in the nuclear sciences."

• **AEC Program.** AEC has put more than $5-million since June 1 into its support program for nuclear training and physical research; $3,508,555 in physical research grants went out under seven new and 54 continued contracts, and another $1,900,321 was granted to 41 colleges and universities expanding their facilities for training nuclear scientists and engineers. The largest training grants—$150,000 each—went to Cornell, Iowa State, Stanford and Worcester Polytechnic Institute. These schools, plus Virginia Polytechnic and Kansas Univ., will install small teaching reactors with the help of this latest round of grants. VPI was awarded $114,000, Kansas $100,000.

• **The Atom's Appeal.** Lewis L. Strauss, former AEC chairman, reported just prior to leaving office July 1 that student and teacher requests for information from AEC have increased sharply this year. Requests through April have totalled 15,120 against only 18,815 for the entire year 1957. They show interest "in all phases of atomic energy" and include requests from "nearly every foreign country." All are answered: some with nuclear kits,

others by copies of speeches or reports, and a "considerable number" by individual letters.

"The Commission recognizes," the Strauss report said, "that behind each inquiry lies a curious mind that may someday make a significant contribution to the world's scientific and technological progress."

• **The University of Washington** has assumed responsibility for a graduate training program at Hanford. The school, established by contract July 1, has been named the University of Washington Center for Graduate Study at Hanford. It supplants the nuclear engineering school conducted by General Electric since 1946 under a cooperative arrangement with the university and other state institutions in the area.

AEC will aid the program with an annual grant—$34,200 the first year. Enrollment preference will be given to employees of AEC and other government agencies, GE, and other AEC contractors.

Initially, classes will be held in the facilities used by the GE school under instructors supplied for the most part by AEC and GE, plus faculty members of the University and cooperating schools. No resident, full-time teaching staff is planned at present. A director to be selected will coordinate instruction and research with work offered at the Seattle campus.

• **Space Technology,** a 16 mm film series prepared by the University of California, Los Angeles, is being made available for a rental fee of $2,300. The film is a 17-program series of lectures by such authorities as Wernher von Braun, Army Ballistic Missile Agency and William H. Pickering, director of the Jet Propulsion Laboratory, California Institute of Technology. The rental fee includes two sets of lecture notes which may be duplicated but not published.

• **GE and Westinghouse** have announced extensive programs for financial support of scientific training. The Westinghouse Educational Foundation disclosed it has committed $75,000 to help Massachusetts Institute of Technology build its research reactor and nuclear laboratory. The Foundation will award a total of $800,000 this year to colleges, universities and individuals. GE has awarded 300 summer fellowships to school teachers for further schooling in science and mathematics.

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NEWSMAKERS

Five Detroit Edison engineers have been named to the Power Reactor Development staff which will operate the Enrico Fermi reactor under construction at Lagoona Beach, Mich. They are: **William C. Morrison,** operating engineer; **Orville E. Homeister,** technical engineer; **Richard G. Rateick,** asst. technical engineer; and **William F. Colbert** and **Eugene H. Newton,** shift engineers.

Stanley B. Roboff, a veteran of 15 years' activity in the nuclear field, has been designated by Sylvania-Corning Nuclear to head up a newly-expanded marketing organization for the firm. As part of SYLCOR's enlarged marketing emphasis, **Bernard Kopelman** has been named director of market development. Kopelman will be charged with development of new markets for existing products and development of new product lines. Roboff's new marketing organization includes three regional managers and a supervisor of marketing service. **Leonard Smiley,** manager for the northern region; **Charles I. Whitman,** eastern region manager; **James O. Vadeboncoeur,** western region manager; and **Robert W. Campbell,** service supervisor. Roboff was with the Manhattan Project and AEC before joining Sylvania in 1952.

Roboff

Kopelman

Chauncey Starr, general manager of Atomics International, has been elected president of the American Nuclear Society, succeeding **Leland J. Haworth,** director of Brookhaven National Laboratory.

Charles P. Yerkes has been named by Vitro Engineering to handle nuclear sales in the company's expanded sales organization.

CREI Atomics Div., Capitol Radio Engineering Institute, has a new director-consultant, Vice Admiral **Charles B. Momsen,** USN (ret.). Momsen is also a consultant to General Dynamics, U. S. Rubber, Raytheon and Coleman Engineering.

Rocketdyne Div., North American Aviation, has brought in two new engineers for its engine development work on a nuclear rocket—Project Rover. **William C. Cooley** has left General Electric's Aircraft Nuclear Propulsion Dept. to join Rocketdyne as assistant program engineer on the Rover program; **Chuk-ching Ma,** formerly of Combustion Engineer, has been assigned responsibility for advanced research and design of nuclear rocket engines.

Nuclear Development Corp. has created a chemistry department, naming **Rene A. Bolomey** to direct it. Bolomey joined NDA from Curtiss-Wright, where he held the same post. Other new NDA employees are **David G. Keller,** personnel director, **James H. Hutton,** advisory engineer; and **Donald S. Kellogg,** consulting engineer (Keller, Hutton and Kellogg were mistakenly reported in this space last month as having joined Nuclear Corp. of America).

Bolomey

The National Bureau of Standards has filled two posts of interest to the atomic energy industry. **Irl C. Schoonover,** chief of mineral products div., has been appointed acting associate director for planning, with control over the Bureau's plans to build a research reactor. **William R. Shields,** Goodyear Atomic, has joined the mass spectrometry section, with responsibility for a lab making precise isotopic abundance measurements of the uranium isotopes.

Irving A. Berstein has been elected president of Controls for Radiation, Inc., Cambridge. He was vice president and technical director.

Max M. Nold, a visiting scientist with the Oak Ridge Institute of Nuclear Studies since May 1955, has been assigned to the Laboratory of Radiation Biology, Cornell Univ. Nold is a

major in the Air Force Veterinary Corps who handled the veterinary radiological health course at ORINS.

Hutchinson

A nuclear fuels-materials specialist, **Ralph O. Hutchison,** has been appointed assistant to **Walter Bedell Smith,** vice board chairman of American Machine & Foundry. In the nuclear field since 1947, Hutchison has served with Carbide and Carbon Chemicals, AEC's Savannah plant, Babcock & Wilcox and Lockheed. He is a former manager of AMF's nuclear fuels dept., Alexandria, Va.

Douglas W. Anderson, Parke Davis & Co., has been elected chairman of the Detroit Nuclear Council, succeeding **Robert W. Hartwell,** Power Reactor Development Co.

Neal W. Kansteiner has been named manager, medical div., Nuclear Measurement Corp. Formerly with Nuclear Corp. of America, he will direct sales and research on a line of medical instruments for detecting and measuring radioactivity.

Wagner

Detroit Edison has promoted **Harvey A. Wagner,** assistant manager of engineering, to manager of system development. He will coordinate and appraise expenditures, handle advance planning, and continue his direction of Edison's atomic power studies. Wagner is a member of the economic and technical committees for Atomic Power Development Associates and was the first director of Edison's nuclear power development dept., created in 1952.

Arthur N. Anderson, reactor engineer, has been elected assistant vice president, Consolidated Edison Co. The firm also named **Gordon Milne,** a designer of the Indian Point reactor, to chief mechanical engineer.

M. W. Kellogg Co. has named **Raymond E. Vener** to direct its industrial research staff.

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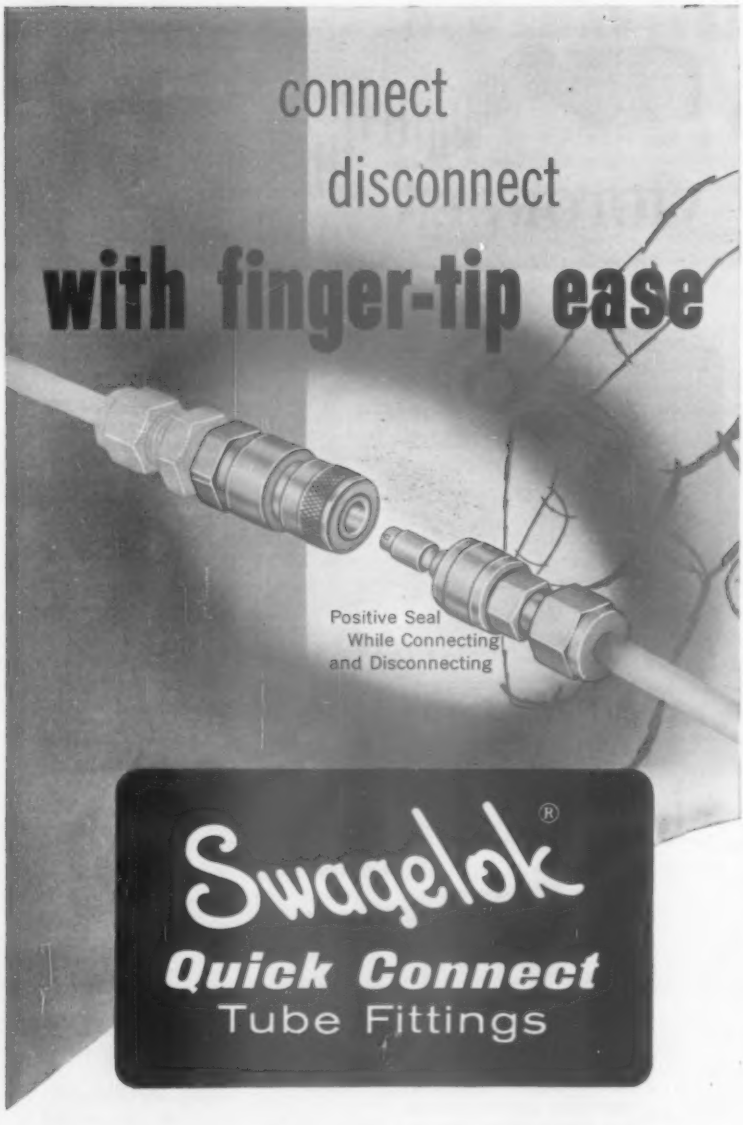

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NUCLEAR CALENDAR

Aug. 10–16—International Congress of Radiation Research, Burlington, Vt. Contact John S. Coleman, 2101 Constitution Ave., Washington 25, D. C.

Sept. 1–13—Second International Conference on Peaceful Uses of Atomic Energy, Geneva, sponsored by United Nations. Contact Sigvard Eklund, United Nations, N. Y.

Sept. 7–11—World Power Conference, Montreal (*The Queen Elizabeth*). Proceedings, in English and French, include trends in nuclear power; post-conference tour of Shippngport avaiilable. Contact T. M. Patterson, c/o Editorial Associates, Suite 220, 1255 University St., Montreal.

Sept. 15–19—International Instrument-Automation Conference, Philadelphia (*Convention Hall*), sponsored by the Instrument Society of America. Program includes two technical sessions on nuclear instruments. Contact Fred J. Tabery, 3443 S. Hill St., Los Angeles.

Sept. 16–20—International Symposium on Nuclear Electronics, Paris (*UNESCO House*). Contact Colloque International Electronique Nucleaire, 10 Avenue Pierre-Larousse, Malakoff (Seine), France.

Nov. 6–7—Sixth annual meeting, Professional Group on Nuclear Science, Institute of Radio Engineers, San Mateo, Calif. (*Villa Hotel*). Four sessions. Contact H. Malcolm Ogle, General Electric, San Jose, Calif.

Nov. 9–12—Annual meeting, Atomic Industrial Forum, Washington, D. C. (*Shoreham*). Contact E. Wiggin, 3 East 54th St., New York 22.

Dec. 1–5—23rd National Exposition of Power and Mechanical Engineering, New York (*Coliseum*). Sponsored by American Society of Mechanical Engineers. Concurrent technical sessions of Nuclear Engineering div., ASME. Contact International Exposition Co., 480 Lexington Ave., New York 17.

Dec. 8–10—Winter meeting, American Nuclear Society, Detroit. Contact Octave DuTemple, 86 E. Randolph St., Chicago.

Jan. 28–29—First International Symposium on Nuclear Fuel Elements, Columbia Univ., New York. Sponsored jointly by Columbia and Sylvania-Corning Nuclear Corp. Contact H. H. Hausner, 730 Fifth Ave., New York 19.

April 5–10—Fifth Nuclear Congress, Cleveland (*Public Auditorium*). Outlines of technical papers due by Oct. 1. Contact T. A. Marshall, Jr., Engineers Joint Council, 29 W. 39th St., New York 18.

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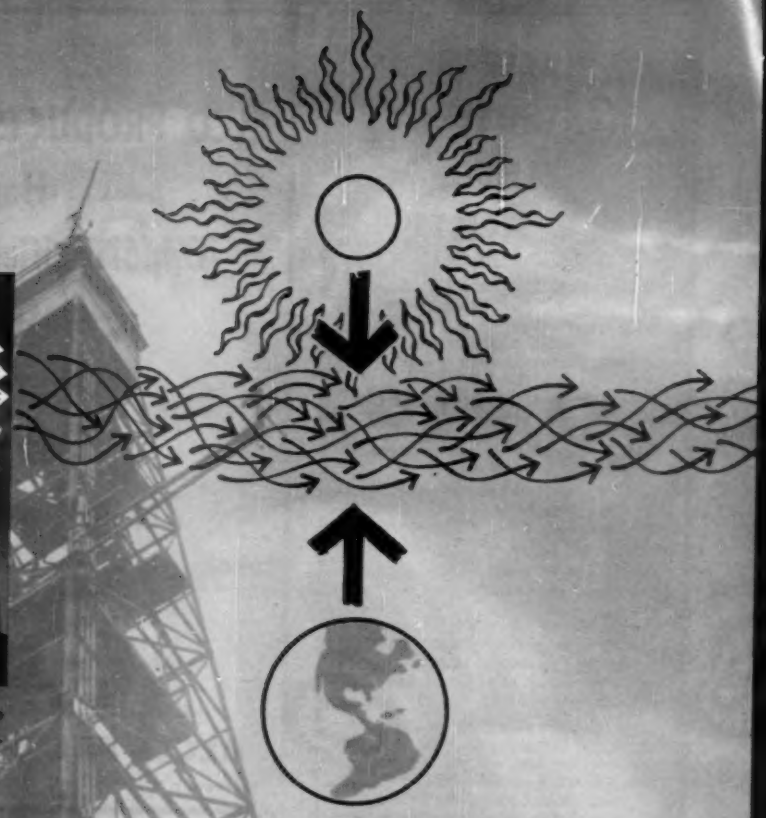

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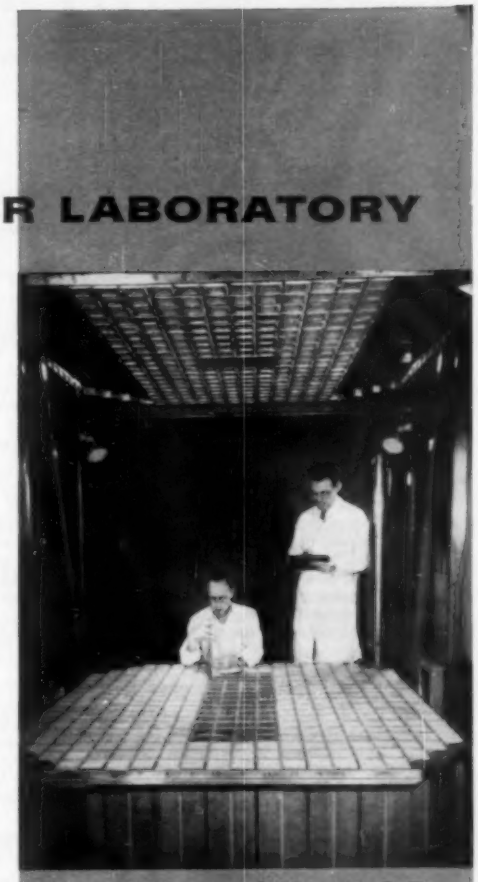

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When an atomic bomb test is made anywhere on earth, radioactivity is scattered into the air and carried about by wind currents. These "hot" atoms fall with precipitation and settle on animals, vegetation, soil, and water. This fallout contains the dangerous radioactive nuclide, strontium-90, and it is desirable to maintain constant knowledge of the amount.

To monitor this fission fallout, the Atomic Energy Commission set up "Project Sunshine." NSEC has been active in the program since 1955, analyzing samples received from all over the world. NSEC recently has been awarded two additional major contracts to measure fallout in Pittsburgh rainfall and in particulate material in the air.

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NSEC has conducted hundreds of radiochemical analyses of experimental nuclear fuel elements, reactor coolant water and other reactor components. NSEC also assists in determining fuel burn-up efficiency, and the rate of gain for breeder reactors. We are taking part in the development of nuclear power plants for aircraft, and are advising many firms which are fabricating fuel elements for various reactors.

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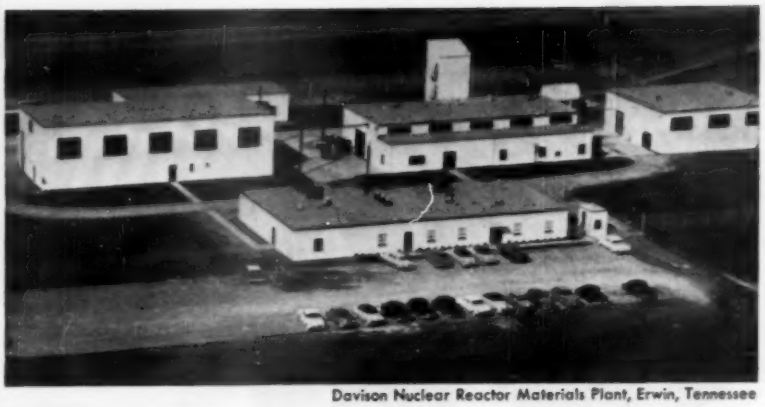

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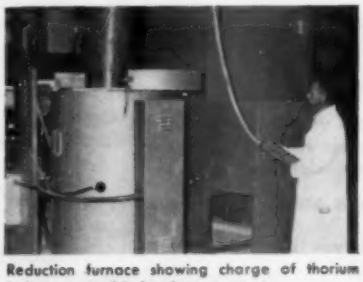
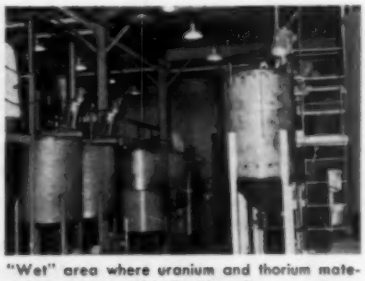
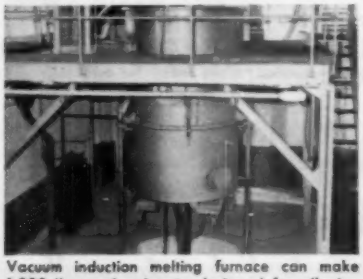


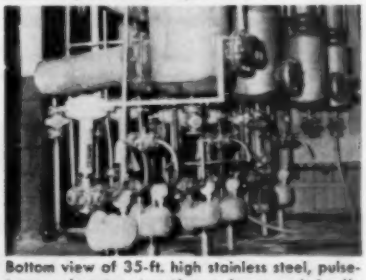
Reduction furnace showing charge of thorium being removed in bomb-type retort.



"Wet" area where uranium and thorium materials are processed in liquid media.



Vacuum induction melting furnace can make 1,200 lb. uranium ingots, designed for alloying and special castings to 3,000 lb.



Bottom view of 35-ft. high stainless steel, pulse-type solvent extraction columns originally developed by AEC.

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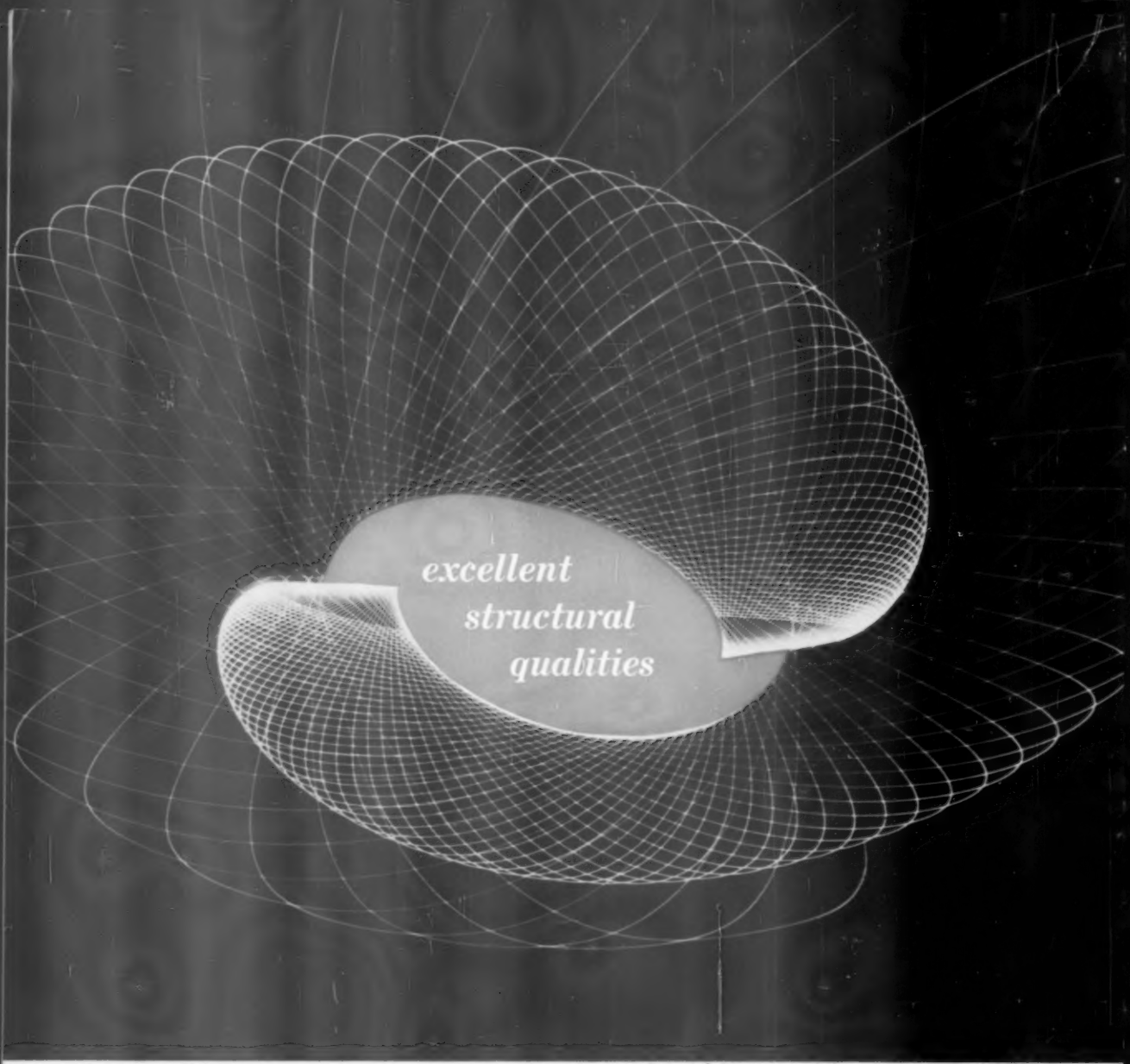

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